



Mechanical Systems Qualification Standard

DOE-STD-1161-2008

August 2012

Reference Guide

The Functional Area Qualification Standard References Guides are developed to assist operators, maintenance personnel, and the technical staff in the acquisition of technical competence and qualification within the Technical Qualification Program (TQP).

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ACRONYMS

ACGIH	American Conference of Government and Industrial Hygienists
AGS	American Glovebox Society
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	as low as reasonably achievable
AMCA	Air Movement and Control Association
API	American Petroleum Institute
AR	actual rate
AS	acquisition strategy
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BCC	body centered cubic
BNA	baseline needs assessment
CAP	corrective action plan
CD	critical decision
CFC	chlorofluorocarbons
CM	configuration management
CO	contracting officer
COR	code of record
CPG	capital programming guide
CTA	central technical authority
dB	decibel
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DSA	documented safety analysis
ECM	electronic control module
ECU	electronic control unit
EG	ethylene glycol
EMA	Engine Manufacturers Association
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
ESF	engineered safety feature
ES&H	environmental, safety, and health
FAQS	functional area qualification standard
FCC	face-centered cubic
FHA	fire hazard analysis

FPD	Federal project director
ftm	feet per minute
gpm	gallons per minute
HDPE	high-density polyethylene
HEPA	high-efficiency particulate air
HVAC	heating, ventilation, and air conditioning
IPT	integrated project team
Kgf	kilogram force
kHz	kilohertz
kPa	kilopascal
KPP	key performance parameters
KSA	knowledge, skill, ability
LCC	life-cycle cost
LMTD	log mean temperature difference (ΔT_{lm})
LTA	less than-adequate
MAWP	maximum allowable working pressure
MORT	management oversight and risk tree
MSDS	material safety data sheets
NDT	nil-ductility transition
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NMMP	nuclear maintenance management program
NNSA	National Nuclear Security Administration
NOP	nozzle opening pressure
NPH	natural phenomena hazard
NPSH	net positive suction head
OMB	Office of Management and Budget
OPMO	Organizational Property Management Office
PAO	polyalphaolefins
PD	positive displacement
PdM	predictive maintenance
PG	propylene-glycol
P&ID	piping and instrumentation diagram
PM	preventive maintenance
PSI	per square inch
PTFE	polytetrafluoroethylene
QA	quality assurance
QAP	quality assurance program
RCA	root cause analysis
RCM	reliability centered maintenance
R&D	research and development
rem	roentgen equivalent man
rpm	revolutions per minute
RTD	resistance temperature detector
RTP	rapid transfer port

SAE	Society of Automotive Engineers
SCC	stress corrosion cracking
SEI	Structural Engineering Institute
SSC	structures, systems, and components
TDC	top dead center
TLV-TWA	threshold limit value-time weighted average
TPC	total project cost
TQP	technical qualification program
TSR	technical safety requirement
TSS	total suspended solids
TXV	thermal expansion valve
ULSD	ultra-low sulfur diesel
μm	micrometer
USQ	unreviewed safety question
UTS	ultimate tensile strength
VE	value engineering
VP	velocity pressure

PURPOSE

The purpose of this reference guide is to provide a document that contains the information required for a Department of Energy (DOE)/National Nuclear Security Administration (NNSA) technical employee to successfully complete the Mechanical Systems Functional Area Qualification Standard (FAQS). Information essential to meeting the qualification requirements is provided; however, some competency statements require extensive knowledge or skill development. Reproducing all the required information for those statements in this document is not practical. In those instances, references are included to guide the candidate to additional resources.

SCOPE

This reference guide has been developed to address the competency statements in the June 2008 edition of DOE-STD-1161-2008, *Mechanical Systems Functional Area Qualification Standard*. The qualification standard for Civil/Structural Engineering contains 36 competency statements.

PREFACE

Competency statements and supporting knowledge and/or skill statements from the qualification standard are shown in contrasting bold type, while the corresponding information associated with each statement is provided below it.

A comprehensive list of acronyms, abbreviations, and symbols is provided at the beginning of this document. It is recommended that the candidate review the list prior to proceeding with the competencies, as the acronyms, abbreviations, and symbols may not be further defined within the text unless special emphasis is required.

The competencies and supporting knowledge, skill, and ability (KSA) statements are taken directly from the FAQS. Most corrections to spelling, punctuation, and grammar have been made without remark. Only significant corrections to errors in the technical content of the discussion text source material are identified. Editorial changes that do not affect the technical content (e.g., grammatical or spelling corrections, and changes to style) appear without remark. When they are needed for clarification, explanations are enclosed in brackets.

Every effort has been made to provide the most current information and references available as of August 2012. However, the candidate is advised to verify the applicability of the information provided. It is recognized that some personnel may oversee facilities that use predecessor documents to those identified. In those cases, such documents should be included in local qualification standards via the TQP.

In the cases where information about an FAQS topic in a competency or KSA statement is not available in the newest edition of a standard (consensus or industry), an older version is referenced. These references are noted in the text and in the bibliography.

This reference guide includes streaming videos to help bring the learning experience alive. To activate the video, click on any hyperlink under the video title. Note: Hyperlinks to video are shown in entirety, due to current limitations of eReaders.

TECHNICAL COMPETENCIES

1. Mechanical systems personnel shall demonstrate a working level knowledge of steady-state heat transfer.

a. Define the following terms:

- Conduction
- Convection
- Radiation
- Thermal conductivity
- Convectivity
- Emissivity

The following definitions are taken from DOE-HDBK-1012/2-92.

Conduction

Conduction involves the transfer of heat by the interaction between adjacent molecules of a material. Heat transfer by conduction is dependent upon the driving “force” of temperature difference and the resistance to heat transfer. The resistance to heat transfer is dependent upon the nature and dimensions of the heat transfer medium. All heat transfer problems involve the temperature difference, the geometry, and the physical properties of the object being studied.

Convection

Convection involves the transfer of heat by the motion and mixing of macroscopic portions of a fluid (that is, the flow of a fluid past a solid boundary). The term “natural convection” is used if this motion and mixing is caused by density variations resulting from temperature differences within the fluid. The term “forced convection” is used if this motion and mixing is caused by an outside force, such as a pump. The transfer of heat from a hot water radiator to a room is an example of heat transfer by natural convection. The transfer of heat from the surface of a heat exchanger to the bulk of a fluid being pumped through the heat exchanger is an example of forced convection.

Video 1. Convection and Conduction

<http://www.bing.com/videos/search?q=conduction&view=detail&mid=3DB4E72C4651A48EBF0C3DB4E72C4651A48EBF0C&first=0>

Radiation

Radiant heat transfer involves the transfer of heat by electromagnetic radiation that arises due to the temperature of a body. Most energy of this type is in the infrared region of the electromagnetic spectrum, although some of it is in the visible region. The term “thermal radiation” is frequently used to distinguish this form of electromagnetic radiation from other forms, such as radio waves, x-rays, or gamma rays. The transfer of heat from a fireplace across a room in the line of sight is an example of radiant heat transfer.

Thermal Conductivity

Thermal conductivity is a measure of a substance's ability to transfer heat through a solid by conduction.

Convectivity

Convectivity is the measure of the absolute value of convection.

Emissivity

Emissivity is a factor by which black body heat transfer is multiplied to take into account that the black body is the ideal case.

Video 2. Emissivity

<http://www.bing.com/videos/search?q=emissivity&view=detail&mid=52A11F67F8A34A1DC04752A11F67F8A34A1DC047&first=0>

b. Discuss Fourier's law.

The following is taken from DOE-HDBK-1012/2-92.

In conduction heat transfer, the most common means of correlation is through Fourier's law of conduction. The law, in its equation form, is used most often in its rectangular or cylindrical form (pipes and cylinders), both of which are presented below:

$$\text{Rectangular: } \dot{Q} \rightarrow k \cdot A \left(\frac{\Delta T}{\Delta x} \right)$$

$$\text{Cylindrical: } \dot{Q} \rightarrow k \cdot A \left(\frac{\Delta T}{\Delta r} \right)$$

where

\dot{Q} = rate of heat transfer (Btu/hr [British thermal unit/hour])

A = cross-sectional area of heat transfer (ft² [square feet])

Δx = thickness of slab (ft [feet])

Δr = thickness of cylindrical wall (ft)

ΔT = temperature difference (°Fahrenheit [°F])

k = thermal conductivity of slab (Btu/ft-hr-°F).

The equations are used in determining the amount of heat transferred by conduction.

c. Describe the factors that contribute to the coefficient of thermal conductivity.

According to DOE-HDBK-1012/2-92, the heat transfer characteristics of a solid material are measured by a property called the thermal conductivity (k) measured in Btu/hr-ft-°F. It is a measure of a substance's ability to transfer heat through a solid by conduction. The thermal conductivity of most liquids and solids varies with temperature. For vapors, it depends upon pressure.

Video 3. Thermal conductivity

<http://www.bing.com/videos/search?q=thermal+conductivity&view=detail&mid=0577B8A55B88AE8B2B4E0577B8A55B88AE8B2B4E&first=0>

Mandatory Performance Activities:

- a. Calculate the heat flux for one-dimensional, steady-state heat transfer through the following types of walls:
- Composite
 - Series
 - Parallel

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity. The following information from DOE-HDBK-1012/2-92 may be useful.

Heat Flux

The rate at which heat is transferred is represented by the symbol \dot{Q} . Common units for heat transfer rate is Btu/hr. Sometimes it is important to determine the heat transfer rate per unit area, or heat flux, which has the symbol \dot{Q}'' . Units for heat flux are Btu/hr-ft². The heat flux can be determined by dividing the heat transfer rate by the area through which the heat is being transferred.

$$\dot{Q}'' = \frac{\dot{Q}}{A}$$

where

$$\dot{Q}'' = \text{heat flux (Btu/hr-ft}^2\text{)}$$

$$\dot{Q} = \text{heat transfer rate (Btu/hr)}$$

$$A = \text{area (ft}^2\text{)}$$

Video 4. Heat flux from temperature distribution

<http://vimeo.com/14781524>

- b. Given data, calculate total heat transfer and local heat flux in a laminar flow system.

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity. The following information from eHow may be helpful.

How to Calculate Heat Transfer

1. Convert all of the units to the units required in the problem. An example problem is, find the heat transfer for 200 g of water that rises in temperature from 23 C to 123 C. The specific heat of water is 4.18 joules/g times degrees Celsius.
2. Write down the beginning and ending temperatures. For instance, if the temperature of water warmed from 23 C to 123 C, then write 23 C for the initial temperature and 123 C for the final temperature.
3. Subtract the first temperature from the final temperature. Be sure that both are in degrees Celsius. In the example problem, 23 is subtracted from 123; 100 C is the change in temperature.
4. Record the mass and the specific heat of the object, and multiply these two by the change in temperature. In the example, multiply 200 g of water times 100 C change in temperature times 4.18. The answer is 83,600 joules. In scientific notation, this is 8.36×10^4 .

c. Given data, calculate the log mean temperature difference for heat exchangers.

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity. The following information from DOE-HDBK-1012/2-92 may be useful.

In heat exchanger applications, the inlet and outlet temperatures are commonly specified based on the fluid in the tubes. The temperature change that takes place across the heat exchanger from the entrance to the exit is not linear. A precise temperature change between two fluids across the heat exchanger is best represented by the log mean temperature difference (LMTD or ΔT_{lm}), defined in the following equation:

$$\Delta T_{lm} = \frac{(\Delta T_2 - \Delta T_1)}{\ln(\Delta T_2 / \Delta T_1)}$$

where

ΔT_2 = the larger temperature difference between the two fluid streams at either the entrance or the exit to the heat exchanger

ΔT_1 = the smaller temperature difference between the two fluid streams at either the entrance or the exit to the heat exchanger.

2. Mechanical systems personnel shall demonstrate a working level knowledge of thermodynamics.

a. Define the following terms:

- **Compression**
- **Isothermic**
- **Isentropic**
- **Adiabatic**

The following definitions are taken from DOE-HDBK-1012/1-92, unless otherwise noted.

Compression

The following is taken from Britannica Online Encyclopedia.

Compression is a decrease in volume of any object or substance resulting from applied stress.

Isothermic

An isothermic process is a process that maintains the temperature constant throughout the system.

Isentropic

An isentropic process is one in which the entropy of the fluid remains constant. This will be true if the process the system goes through is reversible and adiabatic. An isentropic process can also be called a constant entropy process.

Adiabatic

An adiabatic process is one in which there is no heat transfer into or out of the system. The system can be considered to be perfectly insulated.

Video 5. Thermodynamic processes

<http://www.bing.com/videos/search?q=thermodynamic+processes&view=detail&mid=483E19E5AC5E7036D464483E19E5AC5E7036D464&first=0>

b. Discuss entropy and enthalpy as they relate to mechanical systems.

The following is taken from DOE-HDBK-1012/1-92.

Entropy

Entropy (represented by the letter S) is a property of a substance, as are pressure, temperature, volume, and enthalpy. Because entropy is a property, changes in it can be determined by knowing the initial and final conditions of a substance. Entropy quantifies the energy of a substance that is no longer available to perform useful work. Because entropy tells so much about the usefulness of an amount of heat transferred in performing work, the steam tables include values of specific entropy ($s = S/m$) as part of the information tabulated. Entropy is sometimes referred to as a measure of the inability to do work for a given heat transferred. Entropy can be defined as ΔS in the following relationships:

$$\Delta S \Rightarrow \frac{\Delta Q}{T_{abs}}$$

$$\Delta s \Rightarrow \frac{\Delta q}{T_{abs}}$$

where

ΔS = the change in entropy of a system during some process (Btu/°R)

ΔQ = the amount of heat transferred to or from the system during the process (Btu)

T_{abs} = the absolute temperature at which the heat was transferred (°R)

Δs = the change in specific entropy of a system during some process (Btu/pound-mass [lbm] - °R)

Δq = the amount of heat transferred to or from the system during the process (Btu/lbm).

Like enthalpy, entropy cannot be measured directly. Also, like enthalpy, the entropy of a substance is given with respect to some reference value. For example, the specific entropy of water or steam is given using the reference that the specific entropy of water is zero at 32 °F. The fact that the absolute value of specific entropy is unknown is not a problem, because it is the change in specific entropy (Δs) and not the absolute value that is important in practical problems.

Video 6. Entropy

<http://www.bing.com/videos/search?q=Entropy+&view=detail&mid=DDA57793E3EE6D81F6CCDDA57793E3EE6D81F6CC&first=0>

Enthalpy

Specific enthalpy (h) is defined as $h = u + Pv$, where u is the specific internal energy (Btu/lbm) of the system being studied, P is the pressure of the system (pound-force [lbf]/ft²), and v is the specific volume (cubic feet [ft³]/lbm) of the system. Enthalpy is usually used in connection with an open system problem in thermodynamics. Enthalpy is a property of a substance, like pressure, temperature, and volume, but it cannot be measured directly. Normally, the enthalpy of a substance is given with respect to some reference value. For example, the specific enthalpy

of water or steam is given using the reference that the specific enthalpy of water is zero at .01 °C and normal atmospheric pressure. The fact that the absolute value of specific enthalpy is unknown is not a problem, however, because it is the change in specific enthalpy (Δh) and not the absolute value that is important in practical problems. Steam tables include values of enthalpy as part of the information tabulated.

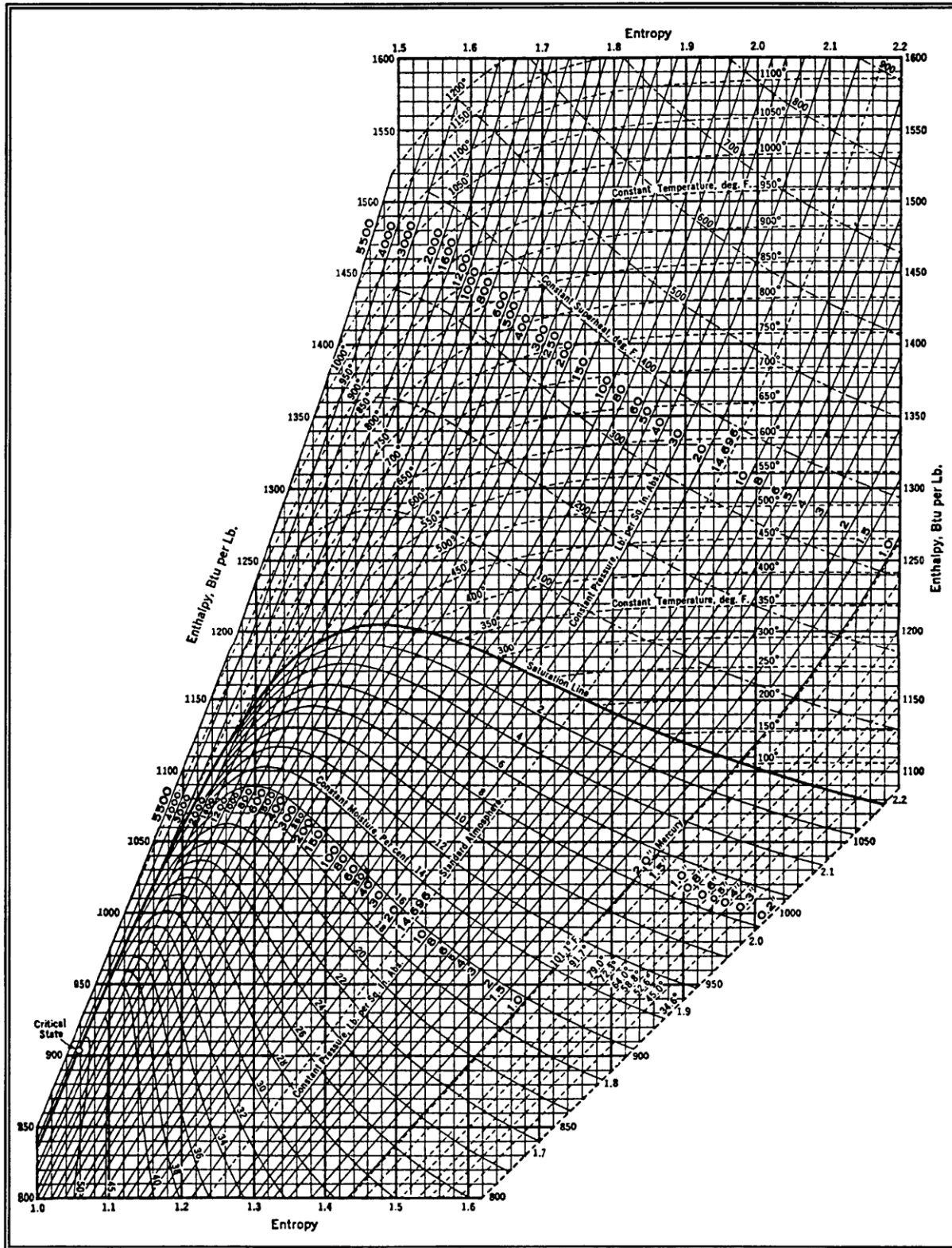
Video 7. Enthalpy

<http://www.bing.com/videos/search?q=Enthalpy+&view=detail&mid=96C11A928F2581928BBD96C11A928F2581928BBD&first=0>

c. Given a Mollier diagram, read and interpret it.

Element c is performance based. The Qualifying Official will evaluate its completion. The following information from DOE-HDBK-1012/1-92 may be useful.

The Mollier diagram shown in figure 1 is a chart on which enthalpy (h) versus entropy (s) is plotted. It is sometimes known as the h-s diagram. The chart contains a series of constant temperature lines, a series of constant pressure lines, a series of constant moisture or quality lines, and a series of constant superheat lines. The Mollier diagram is used only when quality is greater than 50 percent and for superheated steam.



Source: DOE-HDBK-1012/1-92

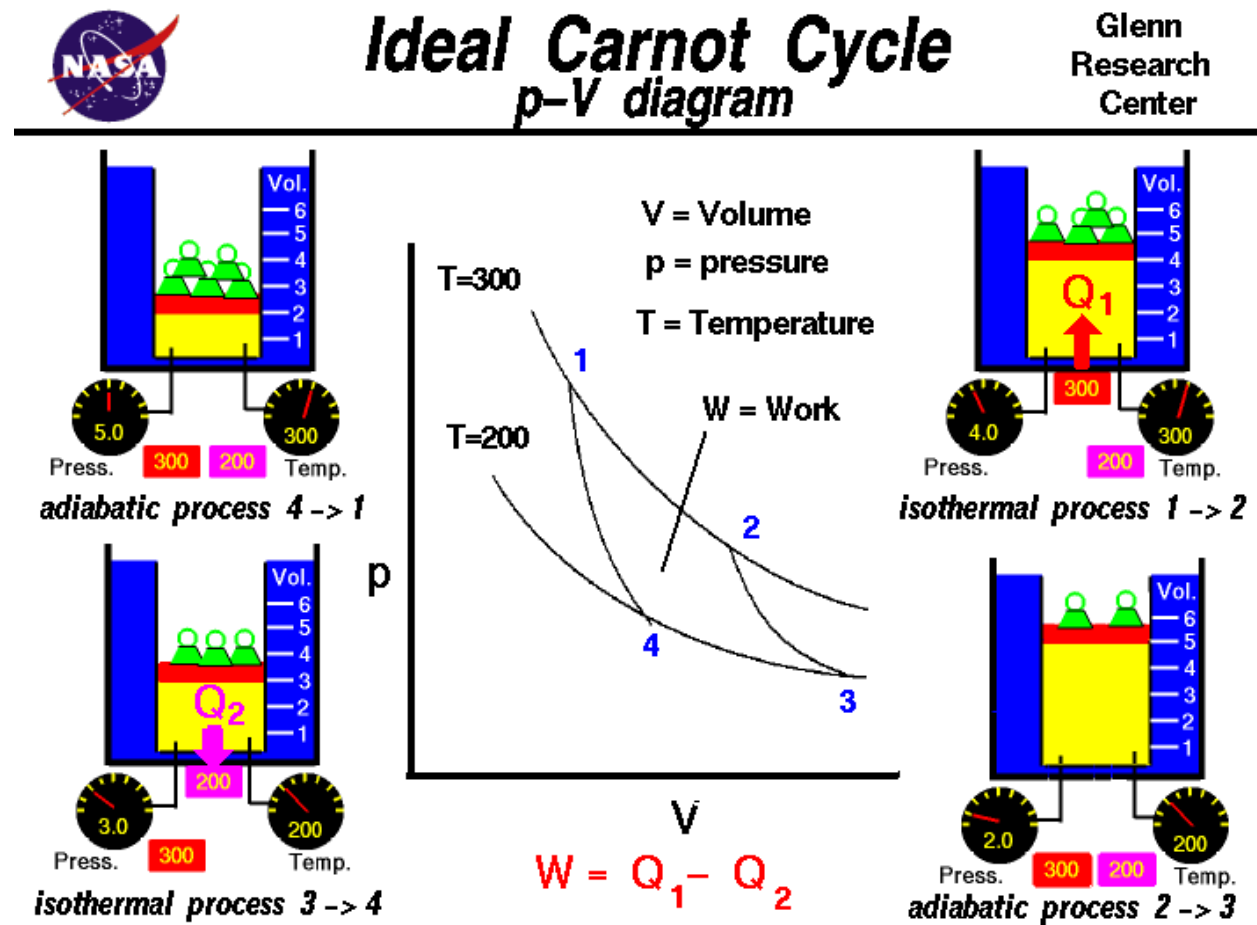
Figure 1. Mollier diagram

d. Define and discuss the following cycles:

- Carnot
- Rankine
- Vapor-refrigeration
- Otto

Carnot Cycle

The following is taken from National Aeronautics and Space Administration, "Ideal Carnot Cycle."



Source: National Aeronautics and Space Administration

Figure 2. Carnot cycle

The Carnot Cycle is one of the fundamental thermodynamic cycles and is described on this web page. A p-V diagram is used to plot the various processes in the Carnot cycle. The cycle begins with a gas, colored yellow on the figure, which is confined in a cylinder, colored blue. The volume of the cylinder is changed by a moving red piston, and the pressure is changed by placing weights on the piston. There are two heat sources; the red one is at a nominal 300 degrees, and the purple one is at 200 degrees. Initially, the gas is in state 1 at high temperature, high pressure, and low volume.

The first process performed on the gas is an isothermal expansion. The 300 degree heat source is brought into contact with the cylinder, and weight is removed, which lowers the pressure in

the gas. The temperature remains constant, but the volume increases. During the process from state 1 to state 2, heat is transferred from the source to the gas to maintain the temperature. Note the heat transfer by Q_1 into the gas.

The second process performed on the gas is an adiabatic expansion. During an adiabatic process no heat is transferred to the gas. Weight is removed, which lowers the pressure in the gas. The temperature decreases and the volume increases as the gas expands to fill the cylinder. During the process from state 2 to state 3 no heat is transferred.

The third process performed on the gas is an isothermal compression. The 200 degree heat source is brought into contact with the cylinder, and weight is added, which raises the pressure in the gas. The temperature remains constant, but the volume decreases. During the process from state 3 to state 4, heat is transferred from the gas to heat source to maintain the temperature. Note the heat transfer by Q_2 away from the gas.

The fourth process performed on the gas is an adiabatic compression. Weight is added, which raises the pressure in the gas. The temperature increases and the volume decreases as the gas is compressed. During the process from state 4 to state 1, no heat is transferred.

At the end of the fourth process, the gas has returned to its original state and the cycle can be repeated as often as desired. During the cycle, work W has been produced by the gas, and the amount of work is equal to the area enclosed by the process curves. From the first law of thermodynamics, the amount of work produced is equal to the net heat transferred during the process:

$$W = Q_1 - Q_2$$

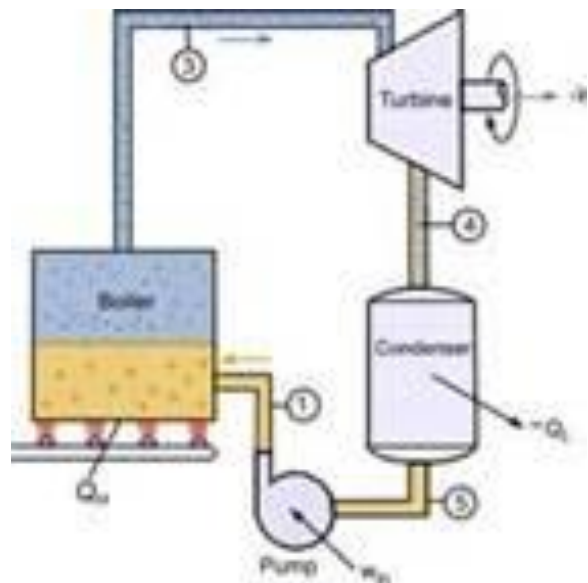
The Carnot cycle has performed as an engine, converting the heat transferred to the gas during the processes into useful work.

Rankine Cycle

The following is taken from DOE-HDBK-1012/1-92.

If a fluid passes through various processes and then eventually returns to the same state it began with, the system is said to have undergone a cyclic process. One such cyclic process used is the Rankine cycle. The Rankine cycle is the hypothetical cycle of a steam engine in which all heat transfers take place at constant pressure and in which expansion and compression occur adiabatically. Figure 3 shows a typical Rankine cycle.

The main feature of the Rankine cycle is that it confines the isentropic compression process to only the liquid phase. This minimizes the amount of work required to attain operating pressures and avoids the mechanical problems associated with pumping a two-phase mixture.



Source: Thermopedia

Figure 3. Rankine cycle

Vapor-Refrigeration Cycle

The following is taken from Kettering University, "Refrigeration and Heat Pump Systems."

In a vapor-refrigeration cycle heat is transferred to the working fluid (refrigerant) in the evaporator and then compressed by the compressor. Heat is transferred from the working fluid in the condenser, and then its pressure is suddenly reduced in the expansion valve. A refrigeration cycle is used to extract energy from a fluid (air) in contact with the evaporator.

It is normally assumed that kinetic and potential energy are negligible, and that the expansion process through the valve is a throttling process.

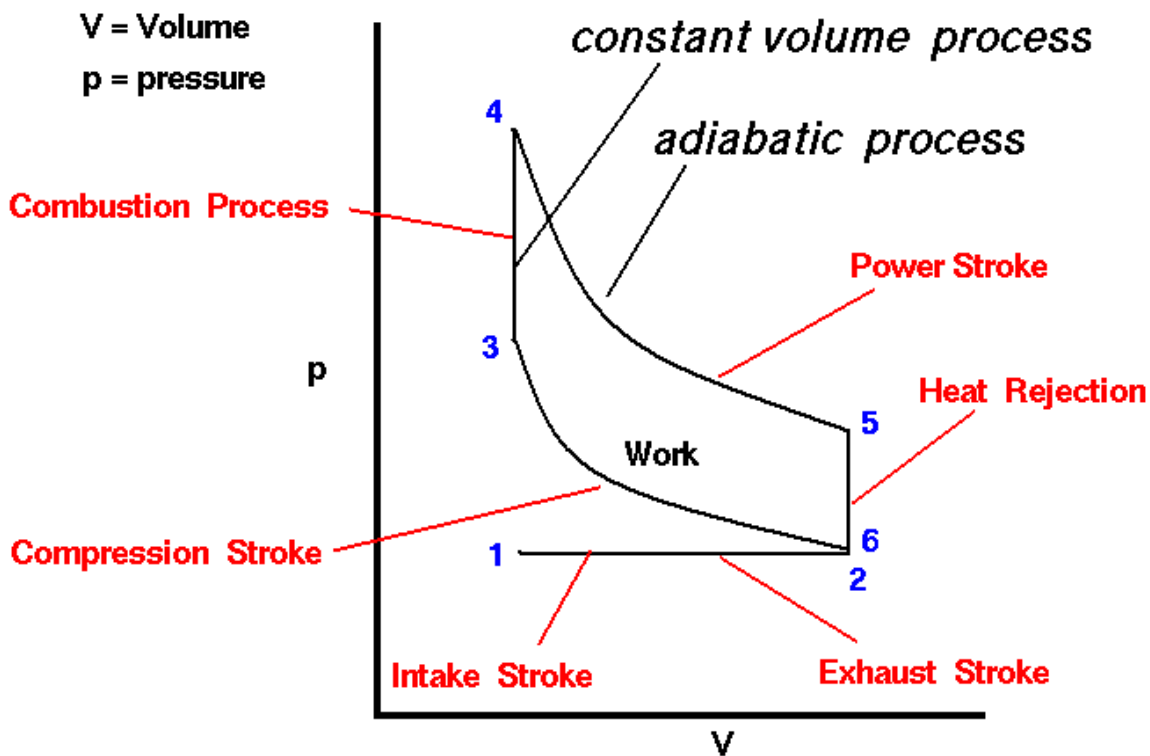
Otto Cycle

The following is taken from National Aeronautics and Space Administration (NASA) Glenn Research Center, "The Ideal Otto Cycle."



Ideal Otto Cycle p - V diagram

Glenn
Research
Center



Source: National Aeronautics and Space Administration (NASA) Glenn Research Center, *The Ideal Otto Cycle*
Figure 4. Otto cycle

The Otto thermodynamic cycle is used in all internal combustion engines. Figure 4 shows a pressure-volume (p - V) diagram of the Otto cycle. Using the engine stage numbering system, begin at the lower left with stage 1 being the beginning of the intake stroke of the engine. The pressure is near atmospheric pressure, and the gas volume is at a minimum. Between stage 1 and stage 2, the piston is pulled out of the cylinder with the intake valve open. The pressure

remains constant, and the gas volume increases as fuel/air mixture is drawn into the cylinder through the intake valve. Stage 2 begins the compression stroke of the engine with the closing of the intake valve. Between stage 2 and stage 3, the piston moves back into the cylinder, the gas volume decreases, and the pressure increases because work is done on the gas by the piston. Stage 3 is the beginning of the combustion of the fuel/air mixture. The combustion occurs very quickly, and the volume remains constant. Heat is released during combustion, which increases both the temperature and the pressure. Stage 4 begins the power stroke of the engine. Between stage 4 and stage 5, the piston is driven towards the crankshaft, the volume is increased, and the pressure falls as work is done by the gas on the piston. At stage 5 the exhaust valve is opened, and the residual heat in the gas is exchanged with the surroundings. The volume remains constant, and the pressure adjusts back to atmospheric conditions. Stage 6 begins the exhaust stroke of the engine during which the piston moves back into the cylinder, the volume decreases, and the pressure remains constant. At the end of the exhaust stroke, conditions have returned to stage 1, and the process repeats itself.

Gas Standard Cycle

The following is taken from *McGraw-Hill Dictionary of Scientific and Technical Terms*. "Gas Standard Cycle."

A gas standard cycle is a sequence in which a gaseous fluid undergoes a series of thermodynamic phases, ultimately returning to its original state. The Brayton cycle is an example of a gas standard cycle. This cycle, also called the Joule or complete expansion diesel cycle, consists of two constant-pressure, isobaric processes interspersed with two reversible adiabatic, isentropic processes.

Mandatory Performance Activities:

a. Given data from a steady-state system, calculate the following:

- Entropy change
- Enthalpy change
- Pressure
- Temperature

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity. The following information from eHow may be helpful.

Entropy Change

CALCULATING THE CHANGE IN ENTROPY

1. Determine the standard entropies of all products and reactants using the entropy table. Given the equation $2\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{CH}_4 + 2\text{O}_2$, the entropies would be 188.7 for H_2O , 213.6 for CO_2 , 186 for CH_4 , and 205 for O_2 .
2. Total the entropies of all of the products. The products are the compounds produced as a result of the chemical reaction. For example, in the equation above, the products are CH_4 and 2O_2 . The total entropy is 186 plus two times 205, which is 596 joules per Kelvin.
3. Total the entropies of all of the reactants. For example, in the equation above, the reactants are $2\text{H}_2\text{O}$ and CO_2 . The total entropy is two times 188.7 plus 213.6 which is 591 joules per Kelvin.

4. Subtract the entropies of the reactants from the entropies of the products. For example, 596 minus 591 is 5 joules per Kelvin, meaning energy entered the system during the reaction.

Enthalpy Change

Enthalpy, h , is a thermodynamic property of fluids used extensively when analyzing flow problems in fields such as fluid dynamics or aerodynamics. It is defined as $u' + p/(\rho)$, where u' is specific internal energy. Enthalpy is used to define two other fluid properties--specific heat at constant pressure, c_p , and specific heat at constant volume, c_v . Using the perfect gas law, $p = (\rho)RT$, and algebraic manipulation, it is possible to derive a simple equation to determine enthalpy: $h = (c_p)T$.

CALCULATING THE CHANGE IN ENTHALPY

1. Determine the temperature change at one location in the fluid being analyzed.
2. Look up the specific heat at constant pressure, c_p , for the fluid being analyzed. Thermodynamic property tables can most easily be found in thermodynamics textbooks as an appendix.
3. Multiply the value for specific heat at constant pressure by the change in temperature recorded earlier. That value is the change in enthalpy.

Pressure

Matter is classified into three states: solid, liquid and gas. The behavior of gas is determined by pressure, volume, and temperature. Changes in these variables can be calculated using Boyle's law, also called the combined gas law, where the starting and ending factors must equal in calculation. Pressure volume can be calculated using the combined gas law equation.

CALCULATING THE CHANGE IN PRESSURE VOLUME

1. Write the following formula and identify the variables:
 $P_1 \times V_1 = (T_1 \times P_2 \times V_2) / T_2$, where
 P_1 is the starting pressure.
 V_1 is the starting volume.
 T_1 is the starting temperature (measured in Kelvin).
 P_2 is the ending pressure.
 V_2 is the ending volume.
 T_2 is the ending temperature (measured in Kelvin).
2. Insert the values of the known variables into the equation; for example:
 P_1 and V_1 are unknown variables.
 $T_1 = 300$ deg. Kelvin (K)
 $P_2 = 1$ atmosphere (atm)
 $V_2 = 1.5$ L
 $T_2 = 325$ deg. Kelvin (K)

Temperature

The change in temperature can be calculated by doing a simple subtraction problem—subtract the original temperature from the new temperature to see how much it changed. The problem gets more complicated, however, if the two temperature values are in different units. For instance, figuring out the change in temperature if in the morning it was 41 degrees Fahrenheit,

but in the afternoon it was 29 degrees Celsius. Actually, 29 degrees Celsius is warmer than 41 degrees Fahrenheit; the difference can be determined by doing a few simple calculations.

CALCULATING THE CHANGE IN TEMPERATURE

1. Obtain the two temperature readings for which the change will be calculated. For example, consider the readings from the introduction; 41 degrees Fahrenheit and 29 degrees Celsius. Before the change in temperature can be calculated, both measurements must be converted to the same unit.
2. Convert the Celsius measurement to Fahrenheit by multiplying it by 9. Example: $29 \times 9 = 261$
3. Divide the answer from the previous step by 5. Example: $261 / 5 = 52.2$
4. Add 32 to the answer from the previous step and the conversion is complete. Example: $52.2 + 32 = 84.2$ degrees Fahrenheit
5. To calculate the change in temperature, subtract the initial temperature from the final temperature. Example: $84.2 \text{ degree Fahrenheit} - 41 \text{ degrees Fahrenheit} = 43.2 \text{ degrees Fahrenheit}$

The temperature from morning to afternoon changed by 43.2 degrees Fahrenheit.

3. **Mechanical systems personnel shall demonstrate a working level knowledge of fluid mechanics.**

a. **Define the following:**

- **Temperature**
- **Pressure**
- **Viscosity**
- **Specific volume**
- **Specific gravity**
- **Capillarity**
- **Cavitation**
- **Laminar flow**
- **Turbulent flow**
- **Uniform flow**
- **Surface tension**

The following definitions are from DOE-HDBK-1012/1-92, /2-92, and /3-92, unless stated otherwise.

Temperature

Temperature is defined as the relative measure of how hot or cold a material is. It can be used to predict the direction that heat will be transferred.

Pressure

Pressure is defined as the force per unit area. Common units for pressure are pounds force per square inch (psi).

Viscosity

Viscosity is a fluid property that measures the resistance of the fluid to deforming due to a shear force. Viscosity is the internal friction of a fluid, which makes it resist flowing past a solid

surface or other layers of the fluid. Viscosity can also be considered to be a measure of the resistance of a fluid to flowing. A thick oil has a high viscosity; water has a low viscosity.

Specific Volume

The specific volume of a substance is the volume per unit mass of the substance. Typical units are ft³/lbm.

Specific Gravity

Specific gravity is a measure of the relative density of a substance as compared to the density of water at a standard temperature. Physicists use 39.2 °F as the standard, but engineers ordinarily use 60 °F. In the International System of Units, the density of water is 1.00 g/cm³ at the standard temperature. Therefore, the specific gravity (which is dimensionless) for a liquid has the same numerical value as its density in units of g/cm³. Since the density of a fluid varies with temperature, specific gravities must be determined and specified at particular temperatures.

Video 8. Specific gravity

http://www.ehow.co.uk/video_4755011_what-specific-gravity-water.html

Capillarity

According to the National Oceanic and Atmospheric Administration's National Weather Service Glossary, capillarity is the degree to which a material or object containing minute openings or passages, when immersed in a liquid, will draw the surface of the liquid above the hydrostatic level. Unless otherwise defined, the liquid is generally assumed to be water.

Cavitation

When the liquid being pumped enters the eye of a centrifugal pump, the pressure is significantly reduced. The greater the flow velocity through the pump the greater this pressure drop. If the pressure drop is great enough, or if the temperature of the liquid is high enough, the pressure drop may be sufficient to cause the liquid to flash to steam when the local pressure falls below the saturation pressure for the fluid that is being pumped. These vapor bubbles are swept along the pump impeller with the fluid. As the flow velocity decreases the fluid pressure increases. This causes the vapor bubbles to suddenly collapse on the outer portions of the impeller. The formation of these vapor bubbles and their subsequent collapse is cavitation.

Video 9. Cavitation

<http://www.bing.com/videos/search?q=cavitation&view=detail&mid=6C7BB67E4FDD9D03A2F66C7BB67E4FDD9D03A2F6&first=0>

Laminar Flow

Laminar flow is also referred to as streamline or viscous flow. These terms are descriptive of the flow because, in laminar flow, 1) layers of water flow over one another at different speeds with virtually no mixing between layers, 2) fluid particles move in definite and observable paths or streamlines, and 3) the flow is characteristic of viscous (thick) fluid or is one in which viscosity of the fluid plays a significant part.

Turbulent Flow

Turbulent flow is characterized by the irregular movement of particles of the fluid. There is no definite frequency as there is in wave motion. The particles travel in irregular paths with no observable pattern and no definite layers.

Uniform Flow

Uniform flow and varied flow describe the changes in depth and velocity with respect to distance. If the water surface is parallel to the channel bottom, flow is uniform and the water surface is at normal depth. Varied flow, or non-uniform flow, occurs when depth or velocity changes over a distance, as in a constriction or over a riffle. Gradually varied flow occurs when the change is small, and rapidly varied flow occurs when the change is large, for example a wave, a waterfall, or the rapid transition from a stream channel into the inlet of a culvert.

Surface Tension

According to the National Institute of Standards and Technology (NIST), Surface Tension, surface tension influences the growth of bubbles in nucleate boiling and the drainage of condensate from certain enhanced condenser surfaces. It is a fluid property required in many two-phase heat transfer correlations.

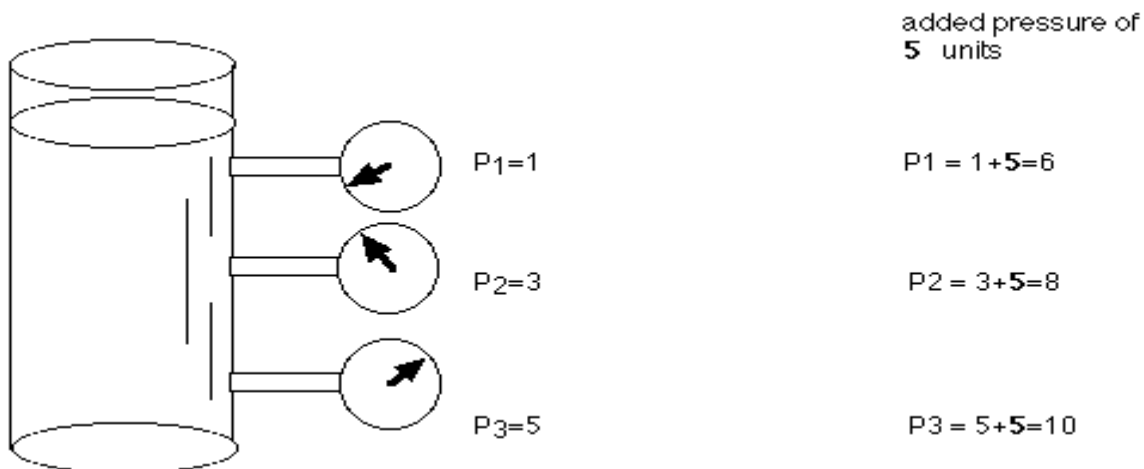
b. Describe the bulk modulus of elasticity and compressibility.

The following is taken from Halliday, Resnick, Walker, *Fundamentals of Physics*.

The bulk elastic properties of a material determine how much it will compress under a given amount of external pressure. The ratio of the change in pressure to the fractional volume compression is called the bulk modulus of the material. The reciprocal of the bulk modulus is called the compressibility of the substance.

c. Describe the effects characterized by Pascal's law of fluid pressure.

The following is taken from National Aeronautics and Space Administration, "Pascal's Principle and Hydraulics."



Source: National Aeronautics and Space Administration, *Pascal's Principle and Hydraulics*

Figure 5. Pascal's law

Pascal's law states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container.

A container, as shown in figure 5, contains a fluid. There is an increase in pressure as the length of the column of liquid increases, due to the increased mass of the fluid above.

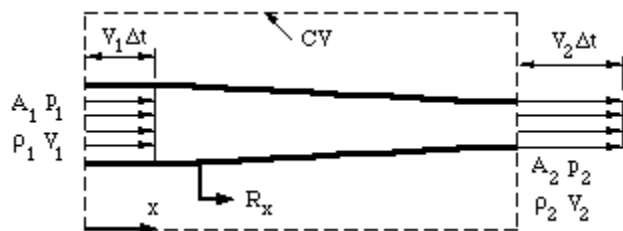
For example, in figure 5, P3 would be the highest value of the three pressure readings, because it has the highest level of fluid above it.

If the container in figure 5 had an increase in overall pressure, that same added pressure would affect each of the gauges the same. For example P1, P2, P3 were originally 1, 3, 5 units of pressure, and 5 units of pressure were added to the system, the new readings would be 6, 8, and 10.

Video 10. Pascal's law

<http://www.veoh.com/watch/v15583234ywrWeEJB>

d. Explain the equation of continuity as it applies to fluid flow.



Source: Princeton University, Continuity Equation

Figure 6. One dimensional duct showing control volume

The following is taken from Princeton University, "Continuity Equation."

When a fluid is in motion, it must move in such a way that mass is conserved. To see how mass conservation places restrictions on the velocity field, consider the steady flow of fluid through a duct. The inflow and outflow are one-dimensional, so that the velocity V and density ρ are constant over the area A as is figure 6.

Now apply the principle of mass conservation. Since there is no flow through the side walls of the duct, what mass comes in over A_1 goes out of A_2 (the flow is steady so that there is no mass accumulation). Over a short time interval Δt ,

$$\text{volume flow in over } A_1 = A_1 V_1 \Delta t$$

$$\text{volume flow out over } A_2 = A_2 V_2 \Delta t$$

Therefore

$$\text{mass in over } A = \rho A_1 V_1 \Delta t$$

$$\text{mass out over } A = \rho A_2 V_2 \Delta t$$

$$\text{So: } \boxed{\rho A_1 V_1 = \rho A_2 V_2}$$

This is a statement of the principle of mass conservation for a steady, one-dimensional flow with one inlet and one outlet. This equation is called the continuity equation for steady one-dimensional flow. For a steady flow through a control volume with many inlets and outlets, the net mass flow must be zero, where inflows are negative and outflows are positive.

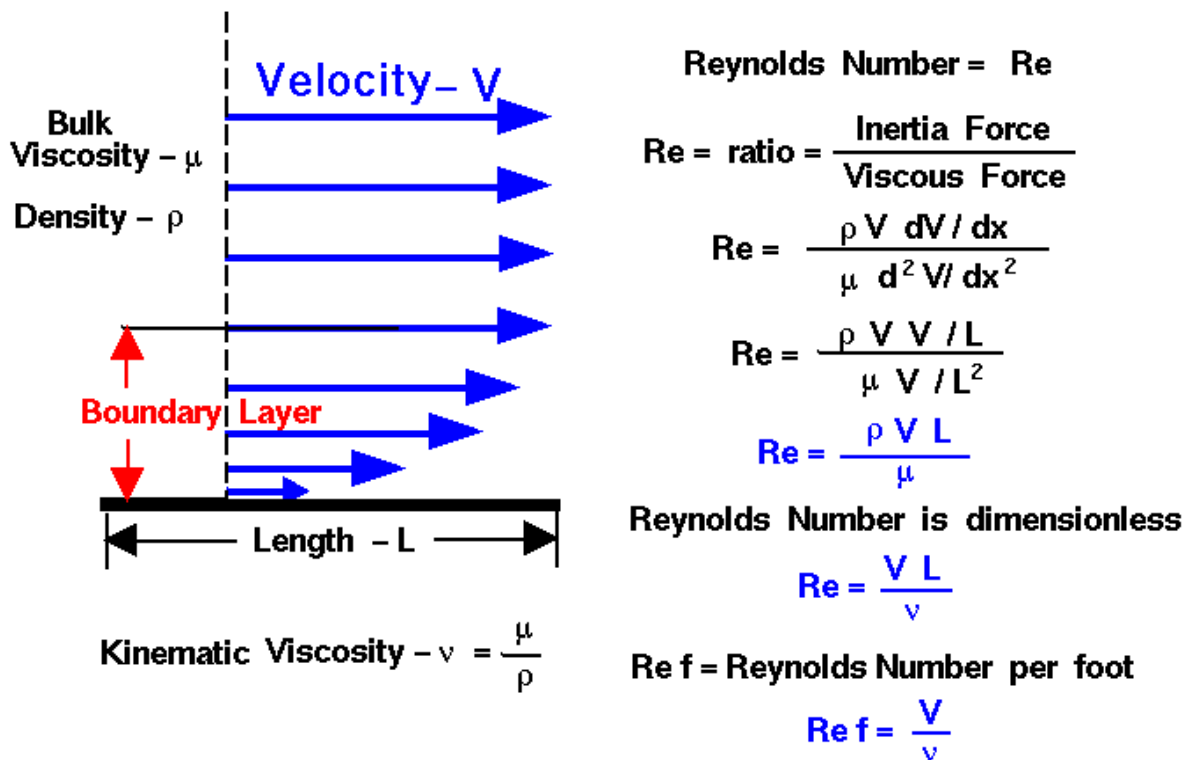
e. Discuss the Reynolds number, including how it is used.

The following is taken from National Aeronautics and Space Administration, "Reynolds Number."



Reynolds Number

Glenn
Research
Center



Source: National Aeronautics and Space Administration, Reynolds Number

Figure 7. Reynolds number

As an object moves through the atmosphere, the gas molecules of the atmosphere near the object are disturbed and move around the object. Aerodynamic forces are generated between the gas and the object. The magnitude of these forces depend on the shape of the object, the speed of the object, the mass of the gas going by the object and on two other important properties of the gas; the viscosity, or stickiness, of the gas and the compressibility, or springiness, of the gas. To properly model these effects, aerodynamicists use similarity parameters that are ratios of these effects to other forces present in the problem. If two experiments have the same values for the similarity parameters, then the relative importance of the forces are being correctly modeled.

Aerodynamic forces depend in a complex way on the viscosity of the gas. As an object moves through a gas, the gas molecules stick to the surface. This creates a layer of air near the surface, called a boundary layer, which, in effect, changes the shape of the object. The flow of gas reacts to the edge of the boundary layer as if it was the physical surface of the object. To make things more confusing, the boundary layer may separate from the body and create an effective shape much different from the physical shape. And to make it even more confusing, the flow

conditions in and near the boundary layer are often unsteady. The boundary layer is very important in determining the drag of an object. To determine and predict these conditions, aerodynamicists rely on wind tunnel testing and very sophisticated computer analysis.

The important similarity parameter for viscosity is the Reynolds number. The Reynolds number expresses the ratio of inertial forces to viscous forces. From a detailed analysis of the momentum conservation equation, the inertial forces are characterized by the product of the density ρ times the velocity V times the gradient of the velocity dV/dx . The viscous forces are characterized by the dynamic viscosity coefficient μ times the second gradient of the velocity d^2V/dx^2 . The Reynolds number Re then becomes:

$$Re = (\rho * V * dV/dx) / (\mu * d^2V/dx^2)$$

The gradient of the velocity is proportional to the velocity divided by a length scale L . Similarly, the second derivative of the velocity is proportional to the velocity divided by the square of the length scale. Then:

$$Re = (\rho * V * V/L) / (\mu * V/L^2)$$

$$Re = (\rho * V * L) / \mu$$

The Reynolds number is a dimensionless number. High values of the parameter (on the order of 10 million) indicate that viscous forces are small and the flow is essentially inviscid. The Euler equations can then be used to model the flow. Low values of the parameter (on the order of 1 hundred) indicate that viscous forces must be considered.

The Reynolds number can be further simplified if the kinematic viscosity ν that is equal to the dynamic viscosity is divided by the density:

$$\nu = \mu/\rho$$

$$Re = V * L/\nu$$

Video 11. Reynolds number

<http://www.bing.com/videos/search?q=reynold%27s+number&view=detail&mid=D26CA4CE3152D2E4F663D26CA4CE3152D2E4F663&first=0>

f. Discuss pressurized and non-pressurized flow.

The following is taken from Geothermal Heat Pump Reviews, “Difference Between Pressurized vs. Non-Pressurized Geothermal Systems.”

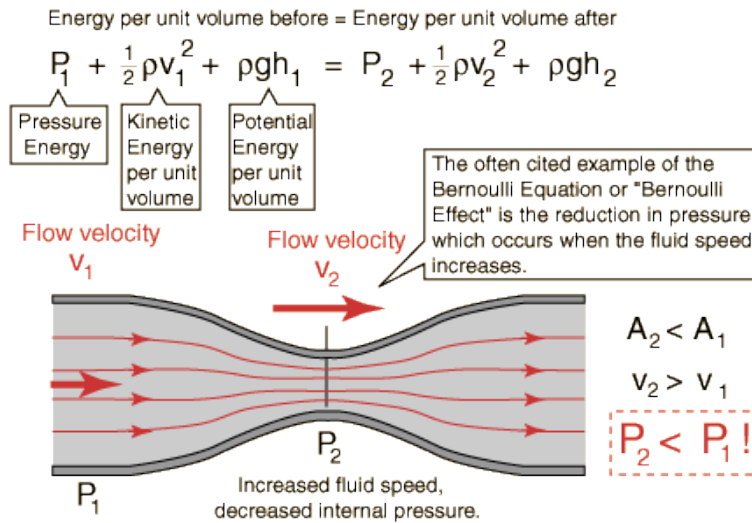
Pressurized pipes exert a positive pressure through the system and are not open to the atmosphere. There are some advantages and disadvantages to this. On the one hand there is much less chance of exposure to anti-freeze, less potential chance of damage to the flow center and it is easier to flush out dirt. The biggest disadvantage is that a pressurized system has a higher initial install cost. It may also need to be pressurized at some point in the future, but that is not a major difficulty.

Non-pressurized pipes, of course, do not have the same positive pressure or sealed environment that the pressurized pipes do. This results in a cheaper initial installation cost and allows excess air to more easily escape from the system. It also provides an easier means to monitor the fluid levels themselves. There are disadvantages. In a non-pressurized system there can be a higher

incidence of bacterial growth and potential dilution of the anti-freeze. There may also be some damage if flushing or purging is done incorrectly.

g. Discuss Bernoulli's equation as it applies to steady-state flow rate calculations.

The following is taken from Georgia State University, Hyperphysics, "Bernoulli's Equation."



The Bernoulli equation can be considered to be a statement of the conservation of energy principle appropriate for flowing fluids. The qualitative behavior that is usually labeled with the term "Bernoulli effect" is the lowering of fluid pressure in regions where the flow velocity is increased. This lowering of pressure in a constriction of a flow path may seem counterintuitive, but

Source: Georgia State University, Hyperphysics, Bernoulli's Equation

Figure 8. Bernoulli's equation

seems less so when pressure is viewed as energy density. In the high velocity flow through the constriction, kinetic energy must increase at the expense of pressure energy.

Video 12. Bernoulli's equation

<http://vimeo.com/22408202>

h. Discuss the ideal gas law as it applies to pressure, volume, and temperature relationships.

The following is taken from Georgia State University, Hyperphysics, "Ideal Gas Law."

An ideal gas is defined as one in which all collisions between atoms or molecules are perfectly elastic and in which there are no intermolecular attractive forces. One can visualize it as a collection of perfectly hard spheres which collide but which otherwise do not interact with each other. In such a gas, all the internal energy is in the form of kinetic energy and any change in internal energy is accompanied by a change in temperature.

An ideal gas can be characterized by three state variables: absolute pressure (P), volume (V), and absolute temperature (T). The relationship between them may be deduced from kinetic theory and is called the

$$\text{Ideal Gas Law} = PV = nRT = nkT$$

where

n = number of moles

R = universal gas constant = 8.3145 J/mol K

N = number of molecules

k = Boltzmann constant = 1.38066×10^{-23} J/K = 8.617385×10^{-5} eV/K

$k = R/N_A$

N_A = Avogadro's number = 6.0221×10^{23} /mol

The ideal gas law can be viewed as arising from the kinetic pressure of gas molecules colliding with the walls of a container in accordance with Newton's laws. But there is also a statistical element in the determination of the average kinetic energy of those molecules. The temperature is taken to be proportional to this average kinetic energy; this invokes the idea of kinetic temperature. One mole of an ideal gas at standard temperature and pressure occupies 22.4 liters.

Video 13. Ideal gas law

http://www.teachertube.com/viewVideo.php?video_id=65432

i. Discuss the Darcy-Weisbach equation.

The following is taken from Oklahoma State University, "Darcy-Weisbach Equation."

The Darcy-Weisbach equation is now considered the best empirical relation for pipe-flow resistance. In terms of head units it is

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \quad (\text{pipe friction})$$

where h_f is the head loss, f is the friction factor, L is the pipe length, V is the average flow velocity, and g is the acceleration of gravity.

In terms of pressure drop, Δp it is

$$\Delta p = f \frac{L}{D} \frac{\rho V^2}{2}$$

where ρ is the fluid density. The Darcy-Weisbach f is a complex function of the Reynolds Number and relative roughness. The Reynolds number, Re is defined as

$$Re = \frac{\rho V D}{\mu}$$

where μ is the fluid absolute viscosity, and D is the pipe diameter. The relative pipe roughness is the ratio of the pipe surface roughness, e to its diameter, D , or e/D .

4. Mechanical systems personnel shall demonstrate a working level knowledge of the concepts, theories, and principles of basic material science.

- a. State the five types of bonding that occur in material and the characteristics of those bonds.

The following descriptions related to chemical bonding are taken from Georgia State University, Hyperphysics, “Chemical Bonding.”

Chemical compounds are formed by the joining of two or more atoms. A stable compound occurs when the total energy of the combination has lower energy than the separated atoms. The bound state implies a net attractive force between the atoms—a chemical bond.

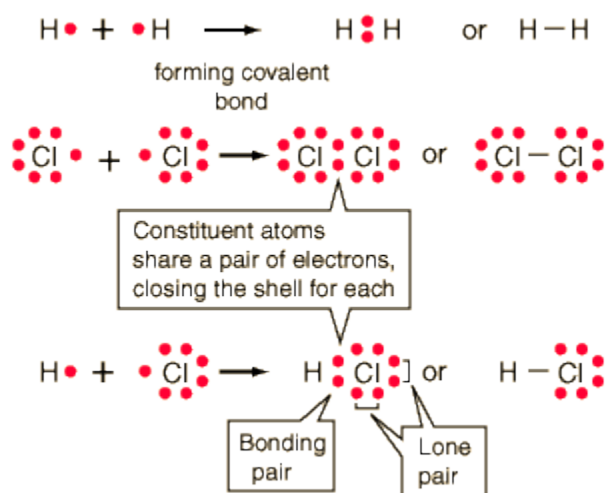
The two extreme cases of chemical bonds are:

- Covalent bond: bond in which one or more pairs of electrons are shared by two atoms
- Ionic bond: bond in which one or more electrons from one atom are removed and attached to another atom, resulting in positive and negative ions which attract each other

Other types of bonds include metallic bonds and hydrogen bonds. The attractive forces between molecules in a liquid can be characterized as van der Waals bonds.

Covalent Bonds

Covalent chemical bonds involve the sharing of a pair of valence electrons by two atoms, in contrast to the transfer of electrons in ionic bonds. Such bonds lead to stable molecules if they share electrons in such a way as to create a noble gas configuration for each atom.



Source: Georgia State University, Hyperphysics, Chemical Bonding, Covalent Bonds

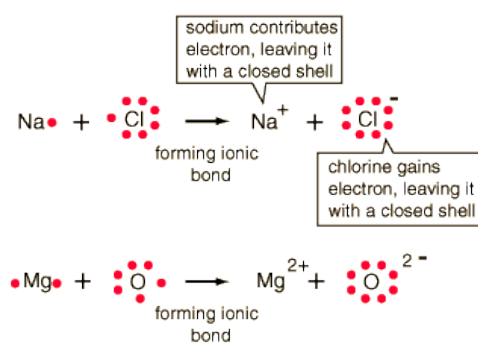
Figure 9. Covalent bond

Hydrogen gas forms the simplest covalent bond in the diatomic hydrogen molecule. The halogens such as chlorine also exist as diatomic gases by forming covalent bonds. The nitrogen and oxygen which makes up the bulk of the atmosphere also exhibits covalent bonding in forming diatomic molecules.

Ionic Bonds

In chemical bonds, atoms can either transfer or share their valence electrons. In the extreme case where one or more atoms lose electrons and other atoms gain them in order to produce a noble gas electron configuration, the bond is called an ionic bond.

Typical of ionic bonds are those in the alkali halides such as sodium chloride.



Source: Georgia State University, Chemical Bonding, Hyperphysics, Ionic Bonds

Figure 10. Ionic bond

Video 14. Chemical bonding basics

<http://vimeo.com/20746749>

Metallic Bonds

The properties of metals suggest that their atoms possess strong bonds, yet the ease of conduction of heat and electricity suggest that electrons can move freely in all directions in a metal. General observations give rise to a picture of “positive ions in a sea of electrons” to describe metallic bonding.

Hydrogen Bonding

Hydrogen bonding differs from other uses of the word “bond” since it is a force of attraction between a hydrogen atom in one molecule and a small atom of high electronegativity in another molecule. That is, it is an intermolecular force, not an intramolecular force as in the common use of the word bond.

When hydrogen atoms are joined in a polar covalent bond with a small atom of high electronegativity such as O, F, or N, the partial positive charge on the hydrogen is highly concentrated because of its small size. If the hydrogen is close to another oxygen, fluorine, or nitrogen in another molecule, then there is a force of attraction termed a dipole-dipole interaction. This attraction or “hydrogen bond” can have about 5 to 10 percent of the strength of a covalent bond.

Hydrogen bonding has a very important effect on the properties of water and ice. Hydrogen bonding is also very important in proteins and nucleic acids and therefore in life processes. The unzipping of DNA is a breaking of hydrogen bonds that help hold the two strands of the double helix together.

Van der Waals Bonding

Water molecules in liquid water are attracted to each other by electrostatic forces, and these forces have been described as van der Waals forces or van der Waals bonds. Even though the water molecule as a whole is electrically neutral, the distribution of charge in the molecule is not symmetrical and leads to a dipole moment—a microscopic separation of the positive and negative charge centers. This leads to a net attraction between such polar molecules which finds expression in the cohesion of water molecules and contributes to viscosity and surface tension. Perhaps it is fair to say that van der Waals forces are what hold water in the liquid state until thermal agitation becomes violent enough to break those van der Waal bonds at 100°C. With cooling, residual electrostatic forces between molecules cause most substances to liquefy and eventually solidify.

Even nonpolar molecules experience some van der Waals bonding, which can be attributed to their being polarizable. Even though the molecules do not have permanent dipole moments, they can have instantaneous dipole moments which change or oscillate with time. These fluctuations of molecular dipole moments lead to a net attraction between molecules which allow nonpolar substances like carbon tetrachloride to form liquids. Examination of the dipole electric field shows that the electric field from one instantaneous dipole will tend to polarize a

neighboring molecule such that it will be attracted - sort of the electrical analog to a bar magnet magnetizing a paper clip so that it will be attracted to the magnet. The weaker van der Waals forces in nonpolar liquids may be manifested in low surface tension and low boiling points.

b. Compare and contrast the properties, characteristics, and applications of stainless steel and those of carbon steel.

Stainless Steel

The following is taken from Wikipedia, “Stainless Steel.”

Stainless steel differs from carbon steel by the amount of chromium present. Unprotected carbon steel rusts readily when exposed to air and moisture. This iron oxide film is active and accelerates corrosion by forming more iron oxide, and due to the dissimilar size of the iron and iron oxide molecules these tend to flake and fall away. Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure, and due to the similar size of the steel and oxide molecules they bond very strongly and remain attached to the surface.

High oxidation-resistance in air at ambient temperature is normally achieved with additions of a minimum of 13 percent chromium, and up to 26 percent is used for harsh environments. The chromium forms a passivation layer of chromium (III) oxide when exposed to oxygen. The layer is too thin to be visible, and the metal remains lustrous. The layer is impervious to water and air, protecting the metal beneath. Also, this layer quickly reforms when the surface is scratched. This phenomenon is called passivation and is seen in other metals, such as aluminum and titanium. Passivation only occurs if the proportion of chromium is high enough and in the presence of oxygen. Corrosion-resistance can be adversely affected if the component is used in a non-oxygenated environment, a typical example being underwater keel bolts buried in timber.

When stainless steel parts such as nuts and bolts are forced together, the oxide layer can be scraped off, causing the parts to weld together. When disassembled, the welded material may be torn and pitted, an effect known as galling. This destructive galling can be best avoided by the use of dissimilar materials for the parts forced together, for example bronze and stainless steel, or even different types of stainless steels, when metal-to-metal wear is a concern. Nitronic alloys reduce the tendency to gall through selective alloying with manganese and nitrogen. Additionally, threaded joints may be lubricated to prevent galling.

Like steel, stainless steel is not a very good conductor of electricity, with a few percent of the electrical conductivity of copper. Ferritic and martensitic stainless steels are magnetic. Austenitic stainless steels are non-magnetic.

Stainless steel's resistance to corrosion and staining, low maintenance and familiar luster make it an ideal material for many applications. There are over 150 grades of stainless steel, of which fifteen are most commonly used. The alloy is milled into coils, sheets, plates, bars, wire, and tubing to be used in cookware, cutlery, hardware, surgical instruments, major appliances, industrial equipment, and as an automotive and aerospace structural alloy and construction material in large buildings. Storage tanks and tankers used to transport orange juice and other food are often made of stainless steel because of its corrosion resistance and antibacterial properties. This also influences its use in commercial kitchens and food processing plants, as it can be steam-cleaned and sterilized and does not need paint or other surface finishes.

Stainless steel is used for jewelry and watches with 316L being the type commonly used for such applications. It can be re-finished by any jeweler and will not oxidize or turn black.

Some firearms incorporate stainless steel components as an alternative to blued or parkerized steel. Some handgun models, such as the Smith & Wesson Model 60 and the Colt M1911 pistol, can be made entirely from stainless steel. This gives a high-luster finish similar in appearance to nickel plating. Unlike plating, the finish is not subject to flaking, peeling, wear-off from rubbing (as when repeatedly removed from a holster), or rust when scratched.

Some automotive manufacturers use stainless steel as decorative highlights in their vehicles.

Carbon Steel

The following is taken from Wikipedia, “Carbon Steel.”

Carbon steel is steel in which the main interstitial alloying constituent is carbon. The American Iron and Steel Institute (AISI) defines carbon steel as the following: “Steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium, or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 1.04 percent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.”

The term “carbon steel” may also be used in reference to steel which is not stainless steel; in this use carbon steel may include alloy steels.

As the carbon content rises, steel has the ability to become harder and stronger through heat treating, but this also makes it less ductile. Regardless of the heat treatment, a higher carbon content reduces weldability. In carbon steels, the higher carbon content lowers the melting point.

MILD AND LOW CARBON STEEL

Mild steel, also called plain-carbon steel, is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15 percent carbon and mild steel contains 0.16–0.29 percent carbon; making it malleable and ductile, but it cannot be hardened by heat treatment. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.

It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm³ (7850 kg/m³ or 0.284 lb/in³) and the Young’s modulus is 210 GPa (30,000,000 psi).

Low carbon steels suffer from yield-point runout where the material has two yield points. The first yield point (or upper yield point) is higher than the second and the yield drops dramatically after the upper yield point. If a low carbon steel is only stressed to some point between the upper and lower yield point then the surface may develop Lüder bands. Low carbon steels contain less carbon than other steels and are easier to cold-form, making them easier to handle.

HIGHER CARBON STEELS

Carbon steels that can successfully undergo heat-treatment have a carbon content in the range of 0.30–1.70 percent by weight. Trace impurities of various other elements can have a significant

effect on the quality of the resulting steel. Trace amounts of sulfur in particular make the steel red-short. Low alloy carbon steel, such as A36 grade, contains about 0.05 percent sulfur and melts around 2599–2800 °F. Manganese is often added to improve the hardenability of low carbon steels. These additions turn the material into a low alloy steel by some definitions, but AISI's definition of carbon steel allows up to 1.65 percent manganese by weight.

c. Discuss the process of general corrosion of iron and steel when they are exposed to water.

The following is taken from Corrosion Doctors, "Steel Corrosion."

Steel Corrosion

Iron and steel, the most commonly used metals, corrode in many media including most outdoor atmospheres. Usually they are selected not for their corrosion resistance but for such properties as strength, ease of fabrication, and cost. These differences show up in the rate of metal lost due to rusting. All steels and low-alloy steels rust in moist atmospheres. In some circumstances, the addition of 0.3 percent copper to carbon steel can reduce the rate of rusting by one quarter or even by one half.

STEEL CATHODIC PROTECTION

The elements copper, phosphorus, chromium, and nickel have all been shown to improve resistance to atmospheric corrosion. Formation of a dense, tightly adhering rust scale is a factor in lowering the rate of attack. The improvement may be sufficient to encourage use without protection, and can also extend paint life by decreasing the amount of corrosion underneath the paint. The rate of rusting will usually be higher in the first year of atmospheric exposure than in subsequent years, and will increase significantly with the degree of pollution and moisture in the air.

Ordinary steels are essentially alloys of iron and carbon with small additions of elements such as manganese and silicon added to provide the requisite mechanical properties. The steels are manufactured from a mixture of pig iron and scrap, which is treated in the molten state to remove excess carbon and other impurities. The steel may be continuously cast into strands or cast into individual ingots. The final product is then produced by rolling, drawing, or forging. During hot rolling and forging the steel surface is oxidized by air and the scale produced, usually termed millscale. In air, the presence of millscale on the steel may reduce the corrosion rate over comparatively short periods, but over longer periods the rate tends to rise. In water, severe pitting of the steel may occur if large amounts of millscale are present on the surface.

STRESS CORROSION CRACKING (SCC) IN PASSIVATING ENVIRONMENTS

Carbon and low alloy steels can suffer from SCC in a wide range of environments that tend to form a protective passivating film of oxide or other species. Cracking will not normally occur when there is a significant corrosion rate. A wide range of environments have been found to cause SCC, including strong caustic solutions, phosphates, nitrates, carbonates, and hot water. The problems are important for both economic and safety reasons.

Caustic cracking of steam-generating boilers was a serious problem in the late 19th century and boiler explosions led to significant loss of life. More recently gas transmission pipelines have cracked in carbonate solutions produced under protective coatings as a result of cathodic protection systems. In this case the crack runs along the length of the pipe, and may propagate

for very long distances by fast fracture. If the gas cloud that is released ignites, the resultant fireball is devastating.

Iron Corrosion

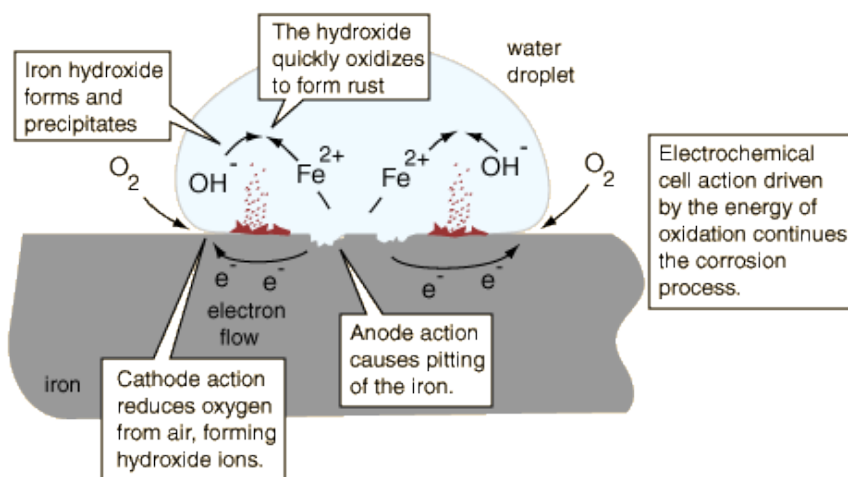
The following is taken from Corrosion Doctors, “Iron Corrosion.”

Cast iron is a generic term that identifies a large family of ferrous alloys. Cast irons are primarily alloys of iron that contain more than 2 percent carbon and 1 percent or more silicon. Low raw material costs and relative ease of manufacture make cast irons the least expensive of the engineering metals. Cast irons may often be used in place of steel at considerable cost savings. The design and production advantages of cast iron include the following:

- Low tooling and production cost
- Ready availability
- Good machinability without burring
- Readily cast into complex shapes
- Excellent wear resistance and high hardness (particularly white irons)
- High inherent damping

Alloying elements can play a dominant role in the susceptibility of cast irons to corrosion attack. Silicon is the most important alloying element used to improve the corrosion resistance of cast irons. Silicon is generally not considered an alloying element in cast irons until levels exceed 3 percent. Silicon levels between 3 and 14 percent offer some increase in corrosion resistance to the alloy, but above about 14 percent Si, the corrosion resistance of the cast iron increases dramatically.

The following is taken from Georgia State University, Hyperphysics, “Corrosion as an Electrochemical Process.”



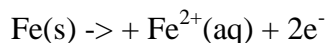
A piece of bare iron left outside where it is exposed to moisture will rust quickly. It will do so even more quickly if the moisture is salt water. The corrosion rate is enhanced by an electrochemical process in which a water droplet becomes a voltaic cell in contact with the metal, oxidizing the iron.

As indicated in the sketch of a water droplet in figure 11, the oxidizing iron supplies

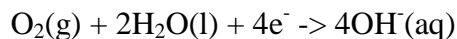
Source: Georgia State University, Hyperphysics, *Corrosion as a Electrochemical Process*

Figure 11. Corrosion

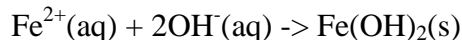
electrons at the edge of the droplet to reduce oxygen from the air. The iron surface inside the droplet acts as the anode for the process



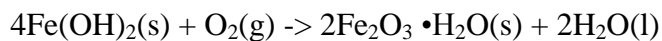
The electrons can move through the metallic iron to the outside of the droplet where



Within the droplet, the hydroxide ions can move inward to react with the iron(II) ions moving from the oxidation region. Iron(II) hydroxide is precipitated.



Rust is then quickly produced by the oxidation of the precipitate.



The rusting of unprotected iron in the presence of air and water is then inevitable because it is driven by an electrochemical process. However, other electrochemical processes can offer some protection against corrosion. For example, magnesium rods can be used to protect underground steel pipes by a process called cathodic protection.

d. Discuss the conditions that can cause galvanic corrosion.

The following is taken from Corrosion Doctors, “Galvanic Corrosion.”

Galvanic corrosion refers to corrosion damage induced when two dissimilar materials are coupled in a corrosive electrolyte.

When a galvanic couple forms, one of the metals in the couple becomes the anode and corrodes faster than it would all by itself, while the other becomes the cathode and corrodes slower than it would alone. For galvanic corrosion to occur, three conditions must be present:

1. Electrochemically dissimilar metals must be present.
2. These metals must be in electrical contact.
3. The metals must be exposed to an electrolyte.

The relative nobility of a material can be predicted by measuring its corrosion potential. The well known galvanic series lists the relative nobility of certain materials in sea water. A small anode/cathode area ratio is highly undesirable. In this case, the galvanic current is concentrated onto a small anodic area. Rapid thickness loss of the dissolving anode tends to occur under these conditions. Galvanic corrosion problems should be solved by designing to avoid these problems in the first place. Galvanic corrosion cells can be set up on the macroscopic level or on the microscopic level. On the microstructural level, different phases or other microstructural features can be subject to galvanic currents.

Video 15. Galvanic corrosion

<http://www.bing.com/videos/search?q=galvanic+corrosion&view=detail&mid=F03A28C4924583227AC6F03A28C4924583227AC6&first=0>

e. Discuss the following types of specialized corrosion:

- **Pitting corrosion**
- **Stress corrosion cracking**
- **Crevice corrosion**
- **Fretting corrosion**

The following descriptions related to types of corrosion are taken from Corrosion Doctors.

Pitting Corrosion

Pitting corrosion is a localized form of corrosion by which cavities or holes are produced in the material. Pitting is considered to be more dangerous than uniform corrosion damage because it is more difficult to detect, predict, and design against. Corrosion products often cover the pits. A small, narrow pit with minimal overall metal loss can lead to the failure of an entire engineering system. Pitting corrosion, which, for example, is almost a common denominator of all types of localized corrosion attack, may assume different shapes.

Suppose that a small cavity exists in the surface of the metal into which oxygen cannot diffuse quickly. A current will be produced between the unaerated area within the cavity, which will become anodic, and the aerated part of the surface outside, which will be the cathode; soluble salt will be formed at the anodic surface within the cavity, but this will not, of course, interfere with further anodic attack. At the mouth of the cavity where the soluble metallic salt from the interior mixes with the alkali from the cathodic part outside, hydroxide may be precipitated, but it will not put a stop to the anodic attack proceeding within. Since the rate of attack is determined by the supply of oxygen to the whole surface outside the pit, and since it is all concentrated on the small area within the pit, the rate at which the corrosion bores into the metal will be very great.

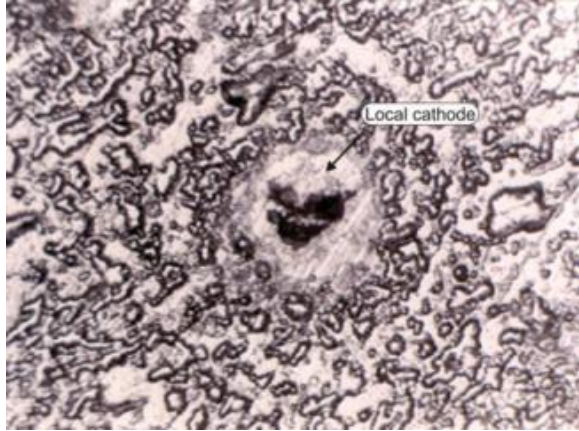
Pitting corrosion can produce pits with the mouth open (uncovered) or covered with a semi-permeable membrane of corrosion products. Pits can be either hemispherical or cup-shaped.

Pitting is initiated by the following:

- Localized chemical or mechanical damage to the protective oxide film
- Water chemistry factors that cause breakdown of a passive film such as acidity, low dissolved oxygen concentrations (which tend to render a protective oxide film less stable) and high concentrations of chloride (as in seawater)
- Localized damage to, or poor application of, a protective coating
- The presence of non-uniformities in the metal structure of the component, e.g. nonmetallic inclusions

Theoretically, a local cell that leads to the initiation of a pit can be caused by an abnormal anodic site surrounded by normal surface which acts as a cathode, or by the presence of an abnormal cathodic site surrounded by a normal surface in which a pit will have disappeared due to corrosion.

In the second case, post-examination should reveal the local cathode, since it will remain impervious to the corrosion attack as in the picture of an aluminum specimen shown in figure 12. Most cases of pitting are believed to be caused by local cathodic sites in an otherwise normal surface.



Source: Corrosion Doctors, Pitting Corrosion

Figure 12. Pitting corrosion

Apart from the localized loss of thickness, corrosion pits can also be harmful by acting as stress risers. Fatigue and SCC may initiate at the base of corrosion pits.

One pit in a large system can be enough to produce the catastrophic failure of that system. An extreme example of such catastrophic failure happened recently in Mexico, where a single pit in a gasoline line running over a sewer line was enough to create great havoc to a city, killing 215 people in Guadalajara.

Stress Corrosion Cracking

Stress corrosion cracking (SCC) is the cracking induced from the combined influence of tensile stress and a corrosive environment. The impact of SCC on a material usually falls between dry cracking and the fatigue threshold of that material. The required tensile stresses may be in the form of directly applied stresses or in the form of residual stresses. The problem itself can be quite complex. The situation with buried pipelines is a good example of such complexity.

Cold deformation and forming, welding, heat treatment, machining, and grinding can introduce residual stresses. The magnitude and importance of such stresses is often underestimated. The residual stresses set up as a result of welding operations tend to approach the yield strength. The build-up of corrosion products in confined spaces can also generate significant stresses and should not be overlooked. SCC usually occurs in certain specific alloy-environment-stress combinations.

Usually, most of the surface remains unattacked, but with fine cracks penetrating into the material. In the microstructure, these cracks can have intergranular or transgranular morphology. Macroscopically, SCC fractures have a brittle appearance. SCC is classified as a catastrophic form of corrosion, as the detection of such fine cracks can be very difficult and the damage not easily predicted. Experimental SCC data is notorious for a wide range of scatter. A disastrous failure may occur unexpectedly, with minimal overall material loss.

The micrograph in figure 13 illustrates intergranular SCC of an Inconel heat exchanger tube with the crack following the grain boundaries.

The micrograph in figure 14 illustrates SCC in a 316 stainless steel chemical processing piping system. Chloride stress corrosion cracking in austenitic stainless steel is characterized by the multi-branched “lightning bolt” transgranular crack pattern.



Source: Corrosion Doctors, SCC

Figure 14. SCC in stainless steel

The most effective means of preventing SCC are: 1) protect properly with the right materials; 2) reduce stresses; 3) remove critical environmental species such as hydroxides, chlorides, and oxygen; 4) and avoid stagnant areas and crevices in heat exchangers where chloride and hydroxide might become concentrated. Low alloy steels are less susceptible than high alloy steels, but they are subject to SCC in water containing chloride ions.



Source: Corrosion Doctors, SCC

Figure 13. Intergranular SCC

CHLORIDE SCC

One of the most important forms of stress corrosion that concerns the nuclear industry is chloride stress corrosion. Chloride stress corrosion is a type of intergranular corrosion and occurs in austenitic stainless steel under tensile stress in the presence of oxygen, chloride ions, and high temperature. It is thought to start with chromium carbide deposits along grain boundaries that leave the metal open to corrosion. This form of corrosion is controlled by maintaining low chloride ion and oxygen content in the environment and use of low carbon steels.

CAUSTIC SCC

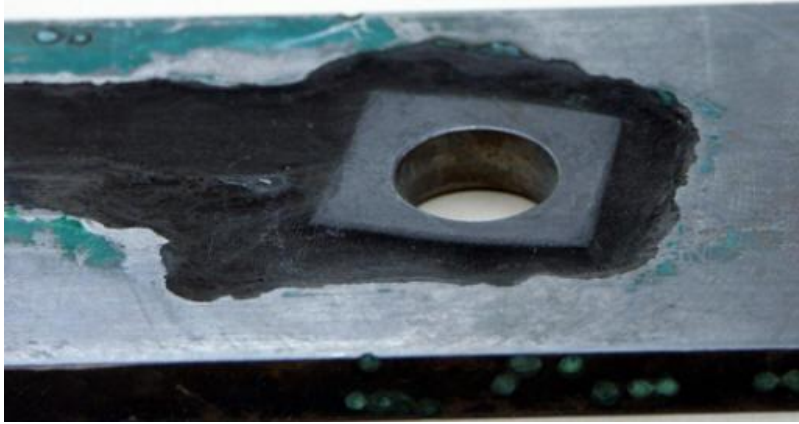
Despite the extensive qualification of Inconel for specific applications, a number of corrosion problems have arisen with Inconel tubing. Improved resistance to caustic stress corrosion cracking can be given to Inconel by heat treating it at 620oC to 705oC, depending upon prior solution treating temperature. Other problems that have been observed with Inconel include wastage, tube denting, pitting, and intergranular attack.

Crevice Corrosion

Crevice corrosion is a localized form of corrosion usually associated with a stagnant solution on the micro-environmental level. Such stagnant microenvironments tend to occur in crevices (shielded areas) such as those formed under gaskets, washers, insulation material, fastener heads, surface deposits, disbonded coatings, threads, lap joints, and clamps. Crevice corrosion is initiated by changes in local chemistry within the crevice such as the following:

- Depletion of inhibitor in the crevice
- Depletion of oxygen in the crevice
- A shift to acid conditions in the crevice
- Build-up of aggressive ion species (e.g. chloride) in the crevice

As oxygen diffusion into the crevice is restricted, a differential aeration cell tends to be set up between crevice and the external surface. The chronology of the aggravating factors leading to a full blown crevice is illustrated in figure 15.



Source: *Corrosion Doctors, Crevice Corrosion*

Figure 15. Full blown crevice corrosion

The cathodic oxygen reduction reaction cannot be sustained in the crevice area, giving it an anodic character in the concentration cell. This anodic imbalance can lead to the creation of highly corrosive micro-environmental conditions in the crevice, conducive to further metal dissolution. This results in the formation of an acidic micro-environment, together with a high chloride ion concentration.

All forms of concentration cell corrosion can be very aggressive, and all result from environmental differences at the surface of a metal. Even the most benign atmospheric environments can become extremely destructive.

The most common form is oxygen differential cell corrosion. This occurs because moisture has a lower oxygen content when it lies in a crevice than when it lies on a surface. The lower oxygen content in the crevice forms an anode at the metal surface. The metal surface in contact with the portion of the moisture film exposed to air forms a cathode.

Fretting Corrosion

Fretting corrosion refers to corrosion damage at the asperities of contact surfaces. This damage is induced under load and in the presence of repeated relative surface motion, as induced for example by vibration. Pits or grooves and oxide debris characterize this damage, typically found in machinery, bolted assemblies and ball or roller bearings. Contact surfaces exposed to vibration during transportation are at the risk of fretting corrosion.

Damage can occur at the interface of two highly loaded surfaces which are not designed to move against each other. The most common type of fretting is caused by vibration. The protective film on the metal surfaces is removed by the rubbing action and exposes fresh, active metal to the corrosive action of the atmosphere.

f. Explain the ion exchange process.

The following is taken from Wikipedia, “Ion Exchange.”

Ion exchange is an exchange of ions between two electrolytes or between an electrolyte solution and a complex. In most cases the term is used to denote the processes of purification, separation, and decontamination of aqueous and other ion-containing solutions with solid polymeric or mineralic ion exchangers.

Typical ion exchangers are ion exchange resins, zeolites, montmorillonite, clay, and soil humus. Ion exchangers are either cation exchangers that exchange positively charged ions (cations) or

anion exchangers that exchange negatively charged ions (anions). There are also amphoteric exchangers that are able to exchange cations and anions simultaneously. However, the simultaneous exchange of cations and anions can be more efficiently performed in mixed beds that contain a mixture of anion and cation exchange resins, or passing the treated solution through several different ion exchange materials.

Ion exchangers can be unselective or have binding preferences for certain ions or classes of ions, depending on their chemical structure. This can be dependent on the size of the ions, their charge, or their structure.

Video 16. Ion exchange

<http://www.bing.com/videos/search?q=ion+exchange&view=detail&mid=B1B0F6BB9141843CDBA3B1B0F6BB9141843CDBA3&first=0>

g. Discuss the following terms:

- Compressibility
- Shear stress
- Tensile stress
- Compressive stress
- Strain
- Proportional limit
- Plastic deformation
- Permanent deformation

Compressibility

The following is taken from Georgia State University, Hyperphysics, “Compressibility in Liquids.

Compressibility is the fractional change in volume per unit increase in pressure. For each atmosphere increase in pressure, the volume of water would decrease 46.4 parts per million. The compressibility k is the reciprocal of the bulk modulus, B .

Shear Stress

The following is taken from Wikipedia, “Shear Stress.”

A shear stress is defined as the component of stress coplanar with a material cross section. Shear stress arises from the force vector component parallel to the cross section. Normal stress, on the other hand, arises from the force vector component perpendicular or antiparallel to the material cross section on which it acts.

The formula to calculate average shear stress is:

$$\tau = \frac{F}{A}$$

where

τ = the shear stress

F = the force applied

A = the cross-sectional area of material with area parallel to the applied force vector.

Tensile Stress

The following is taken from Wikipedia, “Tensile Stress.”

Tensile stress (or tension) is the stress state leading to expansion; that is, the length of a material tends to increase in the tensile direction. The volume of the material stays constant. When equal and opposite forces are applied on a body, then the stress due to this force is called tensile stress.

Therefore in a uniaxial material the length increases in the tensile stress direction and the other two directions will decrease in size. In the uniaxial manner of tension, tensile stress is induced by pulling forces. Tensile stress is the opposite of compressive stress.

Structural members in direct tension are ropes, soil anchors and nails, bolts, etc. Beams subjected to bending moments may include tensile stress as well as compressive stress and/or shear stress.

Tensile stress may be increased until the reach of tensile strength, namely the limit state of stress.

Compressive Stress

The following is taken from Wikipedia, “Compressive Stress.”

Compressive stress is the stress on materials that leads to a smaller volume.

By compressive stress the material is under compression. Compressive stress to bars, columns, etc. leads to shortening.

One can increase the compressive stress until compressive strength is reached. Then materials will react with ductile behavior or with fracture in case of brittle materials.

Strain

The following is taken from The Engineering ToolBox, Stress, Strain, and Young’s Modulus.

Strain is defined as deformation of a solid due to stress and can be expressed as

$$\varepsilon = dl/l_o = \sigma/E$$

where

dl = change of length (m, in)

l_o = initial length (m, in)

ε = unitless measure of engineering strain

E = Young’s modulus (Modulus of Elasticity) (Pa, psi)

Proportional Limit

The following is taken from Buzzle, “Proportional Limit.”

The proportional limit is the maximum amount of stress that an object can handle while still obeying the Hooke’s law. In other words, it is the highest limit of stress that a material may be subjected to, while still maintaining a linear relation with strain.

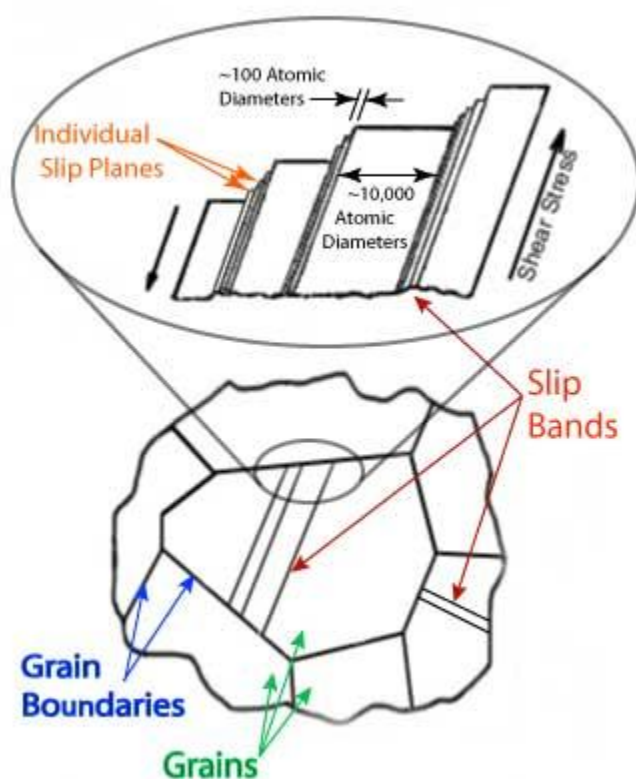
If a curve of stress against strain is plotted, there will be a linear relation between stress and strain, until the yield point is reached. After this point the strain goes on increasing without increase in stress. The highest value of stress, just before the yield point is reached, is known as the proportional limit.

If force is applied beyond this limit, the proportionality relation between stress and strain is no longer maintained. Apply more stress beyond this point, and the material may be permanently deformed. There is no proportional limit formula per se, as the exact value of maximum stress that a material can take is entirely dependent on its internal molecular or crystalline structure.

To conclude, proportional limit is the highest level of stress that a material like a metal can be subjected to, without pushing it beyond the point where it stops obeying the proportionality relation between stress and strain. Studying the properties of materials like their proportional limit and grading them according to their yield strength is one of the most important tasks of a designer and production manager.

Plastic Deformation

The following is taken from NDT Resource Center, “Elastic/Plastic Deformation.”



Source: NDT Resource Center, Elastic/Plastic Deformation

Figure 16. Slip bands

planes to slip past one another at a much lower stress levels. Since the energy required to move is lowest along the densest planes of atoms, dislocations have a preferred direction of travel within a grain of the material. This results in slip that occurs along parallel planes within the grain. These parallel slip planes group together to form slip bands, which can be seen with an optical microscope. A slip band appears as a single line under the microscope, but it is in fact made up of closely spaced parallel slip planes as shown in figure 16.

When a sufficient load is applied to a metal or other structural material, it will cause the material to change shape. This change in shape is called deformation. A temporary shape change that is self-reversing after the force is removed, so that the object returns to its original shape, is called elastic deformation. In other words, elastic deformation is a change in shape of a material at low stress that is recoverable after the stress is removed. This type of deformation involves stretching of the bonds, but the atoms do not slip past each other.

When the stress is sufficient to permanently deform the metal, it is called plastic deformation. Plastic deformation involves the breaking of a limited number of atomic bonds by the movement of dislocations. The force needed to break the bonds of all the atoms in a crystal plane all at once is very great. However, the movement of dislocations allows atoms in crystal

Permanent Deformation

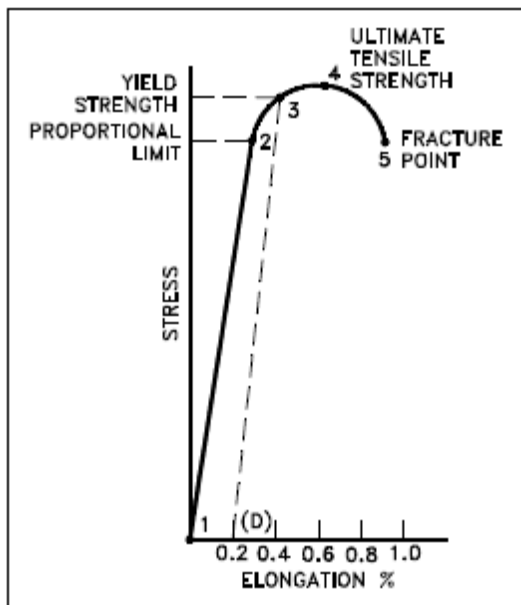
The following is taken from Answers, “Permanent Deformation.”

A permanent deformation is a deformation occurring beyond the yield point so that the structure will not return to its original dimensions after removal of the applied force.

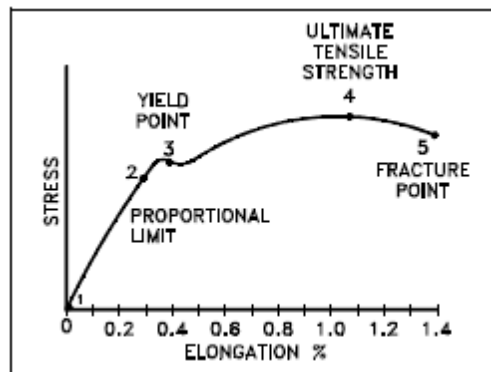
h. Given the stress-strain curves for ductile and brittle material, identify the following points on the curves:

- Proportional limit
- Ultimate strength
- Yield point
- Fracture point

This is a performance-based KSA. The Qualifying Official will evaluate its completion. The following illustrations may be helpful.



Typical Brittle Material Stress-Strain Curve



Typical Ductile Material Stress-Strain Curve

i. Discuss the following terms:

- Strength
- Malleability
- Ductility
- Toughness
- Yield strength
- Hardness
- Ultimate tensile strength

Strength

The following is taken from Wikipedia, “Strength of Materials.”

In materials science, the strength of a material is its ability to withstand an applied stress without failure. The field of strength of materials deals with loads, deformations and the forces acting on a material. A load applied to a mechanical member will induce internal forces within

the member called stresses. The stresses acting on the material cause deformation of the material. Deformation of the material is called strain, while the intensity of the internal forces is called stress. The applied stress may be tensile, compressive, or shear. The strength of any material relies on three different types of analytical method: strength, stiffness, and stability. Strength refers to the load carrying capacity, stiffness refers to the deformation or elongation, and stability refers to the ability to maintain its initial configuration. Material yield strength refers to the point on the engineering stress-strain curve (as opposed to true stress-strain curve) beyond which the material experiences deformations that will not be completely reversed upon removal of the loading. The ultimate strength refers to the point on the engineering stress-strain curve corresponding to the stress that produces fracture.

Malleability

The following is taken from the Columbia Encyclopedia, “Malleability.”

Malleability is the property of a metal describing the ease with which it can be hammered, forged, pressed, or rolled into thin sheets. Metals vary in this respect; pure gold is the most malleable. Silver, copper, aluminum, lead, tin, zinc, and iron are also very malleable. Some heating usually increases malleability. Zinc, for example, at ordinary temperatures is very brittle, but is malleable in the temperature range from about 120°C. to 150°C. Impurities adversely affect the malleability of metals.

Ductility

The following is taken from the Columbia Encyclopedia, “Ductility.”

Ductility is the ability of a metal to plastically deform without breaking or fracturing, with the cohesion between the molecules remaining sufficient to hold them together. Ductility is important in wire drawing and sheet stamping. The metal must neither break nor be scraped off during these processes. Platinum, steel, copper, and tungsten have high ductility. Ductility is a focus of rheology, the study of how materials deform and flow in response to force.

Toughness

The following is taken from NDT Resource Center, “Fracture Toughness.”

Fracture toughness is an indication of the amount of stress required to propagate a preexisting flaw. It is a very important material property since the occurrence of flaws is not completely avoidable in the processing, fabrication, or service of a material/component. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or some combination thereof. Since engineers can never be totally sure that a material is flaw free, it is common practice to assume that a flaw of some chosen size will be present in some number of components and use the linear elastic fracture mechanics approach to design critical components. This approach uses the flaw size and features, component geometry, loading conditions and the material property called fracture toughness to evaluate the ability of a component containing a flaw to resist fracture.

A parameter called the stress-intensity factor (K) is used to determine the fracture toughness of most materials. A Roman numeral subscript indicates the mode of fracture and the three modes of fracture are illustrated in the image to the right. Mode I fracture is the condition in which the crack plane is normal to the direction of largest tensile loading. This is the most commonly encountered mode and, therefore, for the remainder of the material K_I is used.

The stress intensity factor is a function of loading, crack size, and structural geometry. The stress intensity factor may be represented by the following equation:

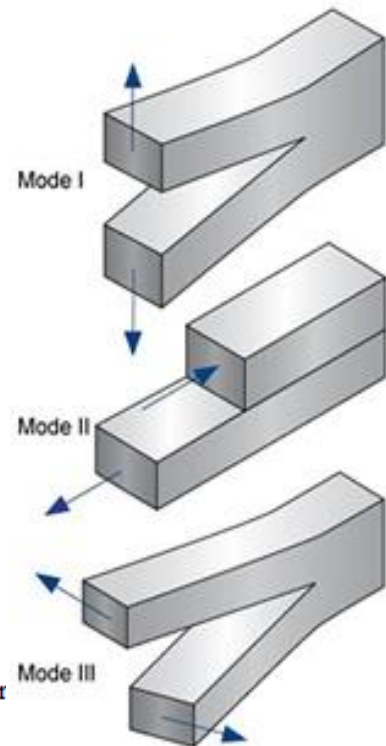
$$K_I = \sigma \sqrt{\pi a \beta}$$

Where: K_I is the fracture toughness in $MPa\sqrt{m}$ ($psi\sqrt{in}$)

σ is the applied stress in MPa or psi

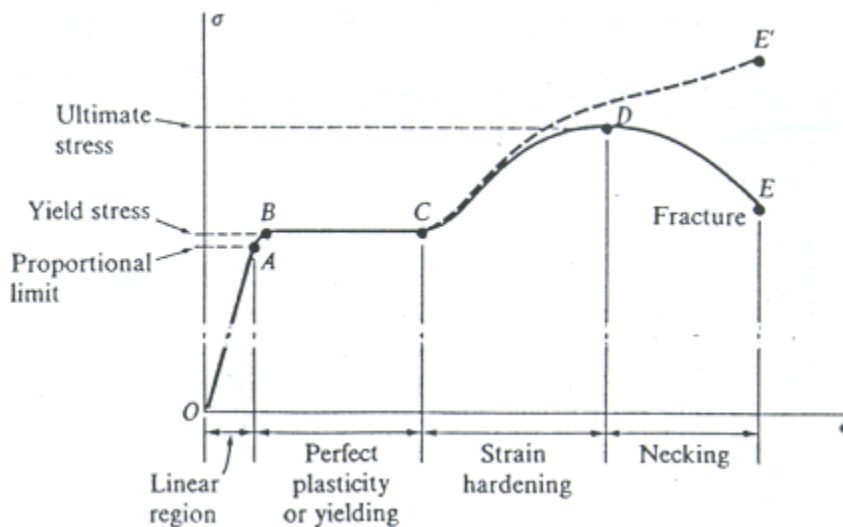
a is the crack length in meters or inches

β is a crack length and component geometry factor that is different for each specimen and is dimensionless.



Yield Strength

The following is taken from Technology, Products, and Processes, “Yield Strength and Heat Treatment.”



Source: Technology, Products, and Processes, Yield Strength and Heat Treatment

Figure 17. Stress-strain diagram

For the general engineering structural design, the yield strength is chosen when 0.2 percent plastic strain has taken place. The 0.2 percent yield strength or the 0.2 percent offset yield strength is calculated at 0.2 percent offset from the original cross-sectional area of the sample ($s=P/A$).

Yield strength is the amount of stress at which plastic deformation becomes noticeable and significant. Figure 17 is an engineering stress-strain diagram in tensile test. Because there is no definite point on the curve where elastic strain ends and plastic strain begins, the yield strength is chosen to be that strength when a definite amount of plastic strain has occurred. For

During yielding stage, the material deforms without an increase in applied load, but during the strain hardening stage, the material undergoes changes in its atomic and crystalline structure, resulting in increased resistance of material to further deformation.

Yield strength is a very important value for use in engineering structural design. To design a component that must support a force during use, the engineer must be sure that the component does not plastically deform, select a material that has high yield strength, or make the component large enough so that the applied force produces a stress that is below the yield strength. In contrast, the tensile strength is relatively unimportant for ductile materials selection and application since too much plastic deformation takes place before it is reached. However, the tensile strength can give some indication of the materials, such as hardness and material defects.

Hardness

The following is taken from the Center for Advanced Life Cycle Engineering, “Hardness.”

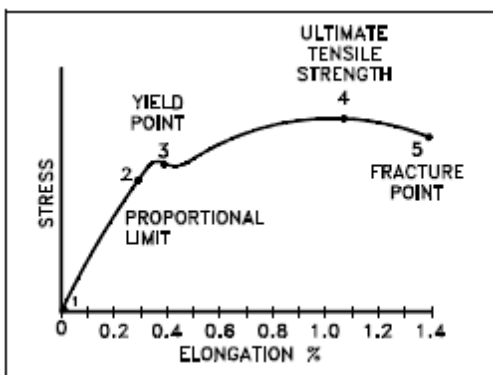
The metals handbook defines hardness as resistance of metal to plastic deformation, usually by indentation. However, the term may also refer to stiffness or temper, or to resistance to scratching, abrasion, or cutting. It is the property of a metal, which gives it the ability to resist being permanently deformed when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation.

Ultimate Tensile Strength

The following is taken from DOE-HDBK-1017-93.

The ultimate tensile strength (UTS) is the maximum resistance to fracture. It is equivalent to the maximum load that can be carried by one square inch of cross-sectional area when the load is applied as simple tension. It is expressed in pounds per square inch.

$$\text{UTS} = \frac{\text{maximum load}}{\text{area of original cross section}} = \frac{P_{\max}}{A_o} = \text{psi}$$



Source: DOE-HDBK-1017-93

Figure 18. Typical stress-strain curve

If the complete engineering stress-strain curve is available, as shown in figure 18, the UTS appears as the stress coordinate value of the highest point on the curve. Materials that elongate greatly before breaking undergo such a large reduction of cross-sectional area that the material will carry less load in the final stages of the test. A marked decrease in cross-section is called “necking.” Ultimate tensile strength is often shortened to “tensile strength” or even to “the ultimate.” “Ultimate strength” is sometimes used but can be misleading; therefore, it is not used in some disciplines.

j. Describe the adverse effects of welding on metal, including the types of stress.

The following is taken from DOE-HDBK-1017-93.

Welding can induce internal stresses that will remain in the material after the welding is completed. In stainless steels, such as type 304, the crystal lattice is face-centered cubic (FCC) (austenite). During high-temperature welding, some surrounding metal may be elevated to between 500°F and 1,000°F. In this temperature region, the austenite is transformed into a body-centered cubic (BCC) lattice structure (bainite). When the metal has cooled, regions surrounding the weld contain some original austenite and some newly formed bainite. A problem arises because the “packing factor is not the same for FCC crystals as for BCC crystals. The bainite that has been formed occupies more space than the original austenite lattice. This elongation of the material causes residual compressive and tensile stresses in the material. Welding stresses can be minimized by using heat sink welding, which results in lower metal temperatures, and by annealing.

k. Discuss the phenomenon of thermal shock.

The following is taken from Wikipedia, “Thermal Shock.”

Thermal shock occurs when a thermal gradient causes different parts of an object to expand by different amounts. This differential expansion can be understood in terms of stress or of strain, equivalently. At some point, this stress can exceed the strength of the material, causing a crack to form. If nothing stops this crack from propagating through the material, it will cause the object’s structure to fail.

Failure due to thermal shock can be prevented by

- reducing the thermal gradient seen by the object through
 - changing its temperature more slowly
 - increasing the material’s thermal conductivity
- reducing the material’s coefficient of thermal expansion
- increasing its strength
- introducing built-in compressive stress; for example, as in tempered glass
- decreasing its Young’s modulus
- increasing its toughness, by
 - crack tip blunting, i.e., plasticity or phase transformation
 - crack deflection

l. Discuss the following terms, including their relationship to material failure:

- **Ductile fracture**
- **Brittle fracture**
- **Nil-ductility transition (NDT) temperature**

Ductile Fracture

The following is taken from Wikipedia, “Fracture.”

In ductile fracture, extensive plastic deformation takes place before fracture. The terms rupture and ductile rupture describe the ultimate failure of tough ductile materials loaded in tension. Rather than cracking, the material pulls apart, generally leaving a rough surface. In this case there is slow propagation and absorption of a large amount of energy before fracture.

Many ductile metals, especially materials with high purity, can sustain very large deformation of 50–100 percent strain before fracture under favorable loading condition and environmental condition. The strain at which the fracture happens is controlled by the purity of the materials. At room temperature, pure iron can undergo deformation up to 100 percent strain before breaking, while cast iron or high-carbon steels can barely sustain 3 percent strain. Because ductile rupture involves a high degree of plastic deformation, the fracture behavior of a propagating crack as modeled above changes fundamentally. Some of the energy from stress concentrations at the crack tips is dissipated by plastic deformation before the crack actually propagates.

The basic steps are: void formation, void coalescence, crack propagation, and failure, often resulting in a cup-and-cone shaped failure surface.

Brittle Fracture

The following is taken from Wikipedia, “Fracture.”

In brittle fracture, no apparent plastic deformation takes place before fracture. In brittle crystalline materials, fracture can occur by cleavage as the result of tensile stress acting normal to crystallographic planes with low bonding (cleavage planes). In amorphous solids, by contrast, the lack of a crystalline structure results in a conchoidal fracture, with cracks proceeding normal to the applied tension.

Nil-Ductility Transition (NDT) Temperature

The following is taken from DOE-HDBK-1017/2-93.

The nil-ductility transition (NDT) temperature, which is the temperature at which a given metal changes from ductile to brittle fracture, is often markedly increased by neutron irradiation. The increase in the NDT temperature is one of the most important effects of irradiation from the standpoint of nuclear power system design. For economic reasons, the large core pressure vessels of large power reactors have been constructed of low carbon steels.

The loss of ductility and increase in the NDT temperature of these vessels is a primary concern to reactor designers because of the increased chance of brittle fracture. Brittle fracture of a material is a failure occurring by crystal cleavage and accompanied by essentially no yielding.

A brittle fracture of a pressure vessel resembles the shattering of glass. Since such a failure would be disastrous, it is necessary to understand the brittle fracture mechanism. During normal reactor operation, the pressure-vessel steel is subject to increasing fluence of fast neutrons and, as a result, the NDT temperature increases steadily. The NDT temperature is not likely to increase sufficiently to approach the temperature of the steel in the pressure vessel. However, as the reactor is being cooled down, the temperature of the vessel may drop below the NDT value while the reactor vessel is still pressurized. Brittle fracture might then occur.

m. Explain fatigue failure and work hardening with respect to material failure.

The following is taken from Metallurgical Consultants, “Metal Fatigue Failures.”

Fatigue Failure

Metal fatigue is caused by repeated cycling of the load. It is a progressive localized damage due to fluctuating stresses and strains on the material. Metal fatigue cracks initiate and propagate in regions where the strain is most severe.

The process of fatigue consists of three stages:

1. Initial crack initiation
2. Progressive crack growth across the part
3. Final sudden fracture of the remaining cross section

STRESS RATIO

The most commonly used stress ratio is R , the ratio of the minimum stress to the maximum stress (S_{min}/S_{max}).

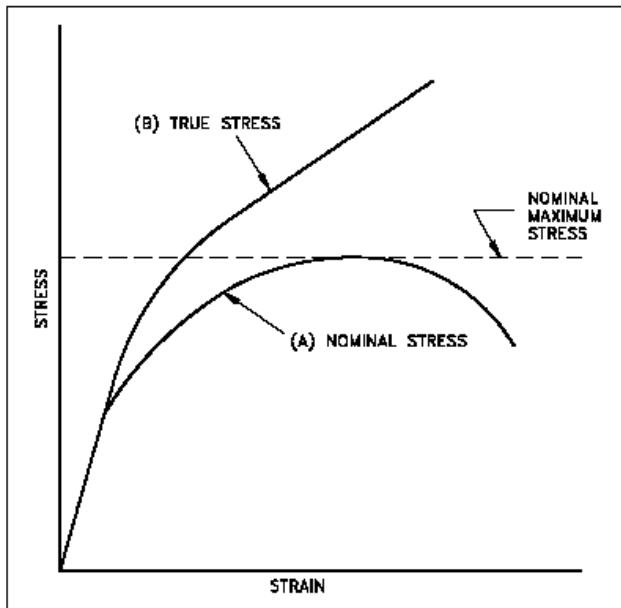
- If the stresses are fully reversed, then $R = -1$.
- If the stresses are partially reversed, R is a negative number less than 1.
- If the stress is cycled between a maximum stress and no load, $R = 0$.
- If the stress is cycled between two tensile stresses, R is a positive number less than 1.

Variations in the stress ratios can significantly affect fatigue life. The presence of a mean stress component has a substantial effect on fatigue failure. When a tensile mean stress is added to the alternating stresses, a component will fail at lower alternating stress than it does under a fully reversed stress.

PREVENTING FATIGUE FAILURE

The most effective method of improving fatigue performance is improvements in design:

- Eliminate or reduce stress raisers by streamlining the part.
- Avoid sharp surface tears resulting from punching, stamping, shearing, or other processes.
- Prevent the development of surface discontinuities during processing.
- Reduce or eliminate tensile residual stresses caused by manufacturing.
- Improve the details of fabrication and fastening procedures.



Source: Engineers Edge, Work Hardening—Strength of Materials

Figure 19. Normal stress-strain curve versus true stress-strain curve

FATIGUE FAILURE ANALYSIS

Metal fatigue is a significant problem because it can occur due to repeated loads below the static yield strength. This can result in an unexpected and catastrophic failure in use.

Because most engineering materials contain discontinuities, most metal fatigue cracks initiate from discontinuities in highly stressed regions of the component. The failure may be due to the discontinuity, design, improper maintenance, or other causes. A failure analysis can determine the cause of the failure.

Work Hardening

The following is taken from Engineers Edge. “Work Hardening—Strength of Materials.”

Work hardening is when a metal is strained beyond the yield point. An increasing stress

is required to produce additional plastic deformation and the metal apparently becomes stronger and more difficult to deform.

When true stress is plotted against true strain, the rate of strain hardening tends to become almost uniform; that is, the curve becomes almost a straight line as shown in figure 19. The gradient of the strain part of the line is known as the strain hardening coefficient or work hardening coefficient, and is closely related to the shear modulus. Therefore, a metal with a high shear modulus will have a high strain or work hardening coefficient. Grain size will also influence strain hardening. A material with small grain size will strain harden more rapidly than the same material with a larger grain size. However, the effect only applies in the early stages of plastic deformation, and the influence disappears as the structure deforms and grain structure breaks down.

Work hardening is closely related to fatigue. Work hardening reduces ductility, which increases the chances of brittle failure.

n. Discuss the effects of radiation on the structural integrity of metals.

The following is taken from Wikipedia, “Radiation Material Science.”

Some of the most profound effects of irradiation on materials occur in the core of nuclear power reactors where atoms comprising the structural components are displaced numerous times over the course of their engineering lifetimes. The consequences of radiation to core components includes changes in shape and volume by tens of percent, increases in hardness by factors of five or more, severe reduction in ductility and increased embrittlement, and susceptibility to environmentally induced cracking. For these structures to fulfill their purpose, a firm understanding of the effect of radiation on materials is required in order to account for irradiation effects in design, to mitigate its effect by changing operating conditions, or to serve as a guide for creating new, more radiation-tolerant materials that can better serve their purpose.

The types of radiation that can alter structural materials consist of neutrons, ions, electrons and gamma rays. All of these forms of radiation have the capability to displace atoms from their lattice sites, which is the fundamental process that drives the changes in structural metals. The inclusion of ions among the irradiating particles provides a tie-in to other fields and disciplines such as the use of accelerators for the transmutation of nuclear waste, or in the creation of new materials by ion implantation, ion beam mixing, plasma assisted ion implantation and ion beam assisted deposition.

The effect of irradiation on materials is rooted in the initial event in which an energetic projectile strikes a target. While the event is made up of several steps or processes, the primary result is the displacement of an atom from its lattice site. Irradiation displaces an atom from its site, leaving a vacant site behind (a vacancy) and the displaced atom eventually comes to rest in a location that is between lattice sites, becoming an interstitial atom. The vacancy interstitial pair is central to radiation effects in crystalline solids and is known as a Frenkel pair. The presence of the Frenkel pair and other consequences of irradiation damage determine the physical effects, and with the application of stress, the mechanical effects of irradiation by the occurring of interstitial phenomena such as swelling, growth, phase transition, segregation, etc.

o. Discuss the need for fracture mechanics and the use of associated mathematical relations.

The following is taken from *Introduction to Fracture Mechanics*, D. Roylance, Massachusetts Institute of Technology (MIT).

The strength of structural metals – particularly steel – can be increased to very high levels by manipulating the microstructure so as to inhibit dislocation motion. Unfortunately, this renders the material increasingly brittle, so that cracks can form and propagate catastrophically with very little warning. An unfortunate number of engineering disasters are related directly to this phenomenon, and engineers involved in structural design must be aware of the procedures now available to safeguard against brittle fracture.

The central difficulty in designing against fracture in high-strength materials is that the presence of cracks can modify the local stresses to such an extent that the elastic stress analyses done so carefully by the designers are insufficient. When a crack reaches a certain critical length, it can propagate catastrophically through the structure, even though the gross stress is much less than would normally cause yield or failure in a tensile specimen. The term “fracture mechanics” refers to a vital specialization within solid mechanics in which the presence of a crack is assumed, and there is a need to find quantitative relations between the crack length, the material’s inherent resistance to crack growth, and the stress at which the crack propagates at high speed to cause structural failure.

When A. A. Griffith (1893–1963) began his pioneering studies of fracture in glass in the years just prior to 1920, he was aware of C. E. Inglis’s work in calculating the stress concentrations around elliptical holes, and naturally considered how it might be used in developing a fundamental approach to predicting fracture strengths. However, the Inglis solution poses a mathematical difficulty: in the limit of a perfectly sharp crack, the stresses approach infinity at the crack tip. This is obviously nonphysical (actually the material generally undergoes some local yielding to blunt the crack tip), and using such a result would predict that materials would have near zero strength: even for very small applied loads, the stresses near crack tips would become infinite, and the bonds there would rupture. Rather than focusing on the crack-tip stresses directly, Griffith employed an energy-balance approach that has become one of the most famous developments in materials science.

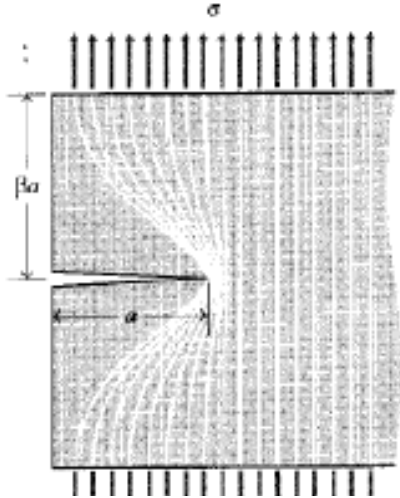
The strain energy per unit volume of stressed material is

$$U = \frac{1}{V} \int f dx = \int_A \frac{f}{L} dx = \int \sigma d\epsilon$$

If the material is linear ($\sigma = E\epsilon$), then the strain energy per unit volume is

$$U = \frac{E\epsilon^2}{2} = \frac{\sigma^2}{2E}$$

When a crack has grown into a solid to a depth a , a region of material adjacent to the free surfaces is unloaded, and its strain energy released. Using the Inglis solution, Griffith was able to compute just how much energy this is.



Source: D. Roylance, MIT, Introduction to Fracture Mechanics

Figure 20. Idealization of unloaded region near crack flanks

A simple way of visualizing this energy release, illustrated in figure 20, is to regard two triangular regions near the crack flanks, of width a and height βa , as being completely unloaded, while the remaining material continues to feel the full stress σ .

The parameter β can be selected so as to agree with the Inglis solution, and it turns out that for plane stress loading $\beta = \pi$. The total strain energy U released is then the strain energy per unit volume times the volume in both triangular regions:

$$U = \frac{\sigma^2}{2E} = \pi a^2$$

strain energy is liberated by crack growth. But in forming the crack, bonds must be broken, and the requisite bond energy is in effect absorbed by the material. The surface energy S associated with a crack of length a (and unit depth) is

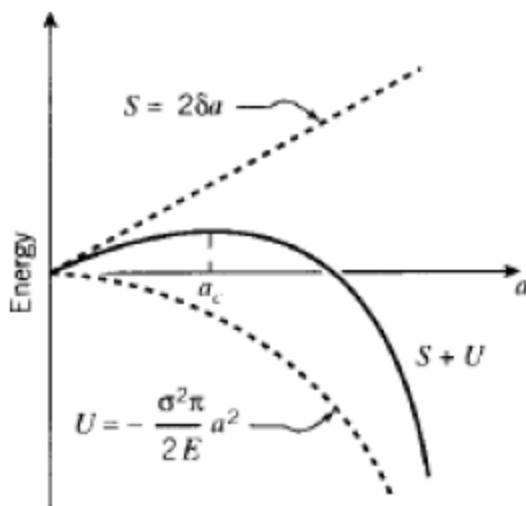
$$S = 2 \gamma a$$

where γ is the surface energy (e.g., Joules/meter²) and the factor 2 is needed since two free surfaces have been formed. As shown in figure 21, the total energy associated with the crack is then the sum of the (positive) energy absorbed to create the new surfaces, plus the (negative) strain energy liberated by allowing the regions near the crack flanks to become unloaded.

As the crack grows longer (a increases), the quadratic dependence of strain energy on a eventually dominates the surface energy, and beyond a critical crack length a_c the system can

lower its energy by letting the crack grow still longer. Up to the point where $a = a_c$, the crack will grow only if the stress is increased. Beyond that point, crack growth is spontaneous and catastrophic.

The value of the critical crack length can be found by setting the derivative of the total energy $S + U$ to zero:



Source: D. Roylance, MIT, Introduction to Fracture Mechanics

Figure 21. The fracture energy balance

$$\frac{\partial(S+U)}{\partial a} = 2\gamma - \frac{\sigma^2 f}{E} \pi a = 0$$

Since fast fracture is imminent when this condition is satisfied, write the stress as σ_f . Solving,

$$\sigma_f = \sqrt{\frac{2E\gamma}{\pi a}}$$

Griffith's original work dealt with very brittle materials, specifically glass rods. When the material exhibits more ductility, consideration of the surface energy alone fails to provide an accurate model for fracture. This deficiency was later remedied, at least in part, independently by G. Irwin and E. Orowan. They suggested that in a ductile material a good deal—in fact the vast majority—of the released strain energy was absorbed not by creating new surfaces, but by energy dissipation due to plastic flow in the material near the crack tip. They suggested that catastrophic fracture occurs when the strain energy is released at a rate sufficient to satisfy the needs of all these energy “sinks,” and denoted this critical strain energy release rate by the parameter G_c . The Griffith equation can then be rewritten in the form

$$\sigma_f = \sqrt{\frac{EG_c}{\pi a}}$$

This expression describes, in a very succinct way, the interrelation between three important aspects of the fracture process: the material, as evidenced in the critical strain energy release rate G_c ; the stress level of and the size, a , of the flaw. In a design situation, one might choose a value of a based on the smallest crack that could be easily detected. Then for a given material with its associated value of G_c , the safe level of stress σ_f could be determined. The structure would then be sized so as to keep the working stress comfortably below this critical value.

5. Mechanical systems personnel shall demonstrate a working level knowledge concerning the selection of appropriate components and materials in support of a mechanical system design or modification.

a. Differentiate between nuclear-grade and non-nuclear-grade materials.

According to DOE G 420.1-1, nuclear grade materials have identified criteria that must be met to allow for their use in nuclear systems. There is a higher level of rigor for nuclear parts. This rigor is usually described in appropriate quality control documents for the nuclear grade materials. Non-nuclear materials may also have quality control requirements, but these requirements are not as stringent as nuclear material quality requirements.

b. Discuss how the following material properties affect performance in different applications:

- Corrosion resistance
- Weight
- Erosion resistance
- Strength
- Cost
- Reactivity
- Composition/alloy
- Ductility
- Brittleness

- **Weldability**
- **Machinability**

Corrosion Resistance

The following is taken from Corrosion Doctors, “Corrosion Resistance.”

The additional cost usually associated with choosing increased corrosion resistance during the selection process is invariably less than that due to product contamination or lost production and high maintenance costs due to premature failure. Without adequate corrosion resistance, or corrosion allowance, components often fall short of the expected design life.

A common form of representing the corrosion resistance of materials is what is known as an isocorrosion diagram. These diagrams are two-dimensional representations of three dimensional corrosion data. Isocorrosion diagrams present corrosion behavior as a function of corrosive concentration (usually the abscissa) and temperature. The use of the prefix “iso” refers to lines (or regions) of constant corrosion behavior across variations in concentration and temperature.

However, it should be emphasized that there are a number of determining criteria for corrosion to occur in actual process conditions which cannot be introduced in iso-corrosion diagrams. The result is that the use of such diagrams to select a material may be inaccurate and sometimes catastrophic. A more reliable methodology to select material and evaluate corrosion risks may be provided by software systems such as CorrIntel™.

Weight

According to Wikipedia, specific weight can be used in mechanical engineering to determine the weight of a structure designed to carry certain loads while remaining intact and remaining within limits regarding deformation.

Erosion Resistance

According to CRC Press, erosion resistance is the ability of a coating to withstand gradual wearing away by chalking or by the abrasive action of water or windborne particles of grit. The degree of resistance is dependent upon the amount of coating retained.

Strength

The following is taken from Wikipedia, “Strength of Materials.”

Mechanics of materials, also called strength of materials, is a subject which deals with the behavior of objects withstanding stresses and strains.

The study of strength of materials often refers to various methods of calculating stresses in structural members, such as beams, columns and shafts. The methods employed to predict the response of a structure under loading and its susceptibility to various failure modes may take into account various properties of the materials other than material yield strength and ultimate strength; for example, failure by buckling is dependent on material stiffness and thus Young’s modulus.

Cost

The following is taken from the Engineer’s Handbook, “Cost.”

A materials cost is also generally a limiting factor. While cost is universally recognized and perhaps the easiest of all properties to understand there are specific cost considerations for materials selection. Just as materials and their processing go hand in hand so do material costs

and processing costs. Understanding the entire processing sequence is critical to accurately evaluating the true cost of a material.

Reactivity

The following is taken from Texas A&M University, “Highly Reactive Materials.”

Though it is not possible to give an exact list of chemical components that will be explosive, it is possible to specify some general structural features that are often associated with high levels of reactivity or instability. These can be described based on a specific chemical group or on the bonding systems seen in the various molecular structures. Chemical names that include in part names such per-, peroxy, azo- and acetylide should cause consideration of the possibility of fragile bonds of peroxides, azides and acetylides. Another warning sign is an organic molecule with a large amount of bonded oxygen which could lead to a large volume release of gas and energy on decomposition.

Composition/Alloy

The following is taken from Key to Metals, “Metal Composition.”

Generally, all metals can be classified as ferrous, non-ferrous and alloys.

The ferrous group of metals is composed mainly of iron. They may have small amounts of other metals or other elements added such as carbon, manganese, nickel, chromium, silicon, titanium, tungsten etc., to give the required properties.

The non-ferrous group is composed of metals that do not contain any iron as a component. The common pure metals are: aluminum, copper, lead, zinc, tin, silver and gold.

An alloy is a new metal which is formed by mixing two or more metals and sometimes other elements together.

The most used metals are: iron, aluminum, copper, titanium, zinc, magnesium, etc.

Iron is the basic component of steel. When carbon, a nonmetal, is added to iron in amounts to 2.1 percent, the result is an alloy known as steel.

Steel is an alloy composed of iron and other elements such as carbon, manganese, phosphorus, sulfur, nickel, chromium, tungsten, niobium (columbium), titanium etc. Each element that is added to the basic constituent of iron has some effect on the properties of the steels. The alloying additions are responsible for many differences between the various types or grades of steels. Based on carbon content, the steels are divided into three main groups: low carbon steels /AISI1005 to AISI 1026, IF, HSLA, TRIP, TWIP steels etc/, middle carbon steels /AISI 1029 to AISI 1053/, and high carbon steels /AISI1055 to AISI1095/.

The most widely used non-ferrous metals are aluminum, copper, titanium, gold, etc.

The aluminum industry uses aluminum as cast and wrought aluminum alloys. These two classes can be further subdivided into families of alloys based on chemical composition and on temper designation.

Ductility

The following is taken from the Engineer’s Handbook, “Ductility.”

Ductility is a measure of how much deformation or strain a material can withstand before breaking. The most common measure of ductility is the percentage of change in length of a

tensile sample after breaking. This is generally reported as % El or percent elongation. The R.A. or reduction of area of the sample also gives some indication of ductility.

Brittleness

The following is taken from Properties of Metals, “Brittleness.”

Brittleness, a mechanical property of metals, is the property of a metal to bend or deform without breaking or shattering.

Video 17. Ductility versus brittleness

<http://www.bing.com/videos/search?q=ductility&view=detail&mid=078784CE98F3F77BAB1A078784CE98F3F77BAB1A&first=0>

Weldability

The following is taken from Wikipedia, “Weldability.”

The weldability, also known as joinability, of a material refers to its ability to be welded. Many metals and thermoplastics can be welded, but some are easier to weld than others. A material’s weldability is used to determine the welding process and to compare the final weld quality to other materials.

Weldability is often hard to define quantitatively, so most standards define it qualitatively. For instance the International Organization for Standardization (ISO) defines weldability in ISO standard 581-1980 as: “Metallic material considered to be susceptible to welding to an established extent with given processes and for given purposes when welding provides metal integrity by a corresponding technological process for welded parts to meet technical requirements as to their own qualities as well as to their influence on a structure they form.”

Machinability

The following is taken from The Engineering ToolBox, “Machinability.”

Machinability of a material can be defined as the ease with which it can be machined. Machinability depends on the physical properties and the cutting conditions of the material.

Machinability can be expressed as a percentage or a normalized value. The AISI has determined AISI No. 1112 carbon steel a machinability rating of 100 percent.

Video 18. Machinability

<http://www.bing.com/videos/search?q=machinability+in+a+metal&view=detail&mid=D6113E33F73D7C378CCFD6113E33F73D7C378CCF&first=0>

c. Identify and discuss the various methods of verifying the properties of selected materials, including:

- Brinell hardness test
- Rockwell hardness test
- V-notch test
- Drop-weight test
- Tension test
- Fatigue test
- Creep test
- Corrosion test
- Crack propagation testing

Brinell Hardness Test

The following is taken from Wikipedia, “Brinell Scale.”

The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. It is one of several definitions of hardness in materials science.

Proposed by Swedish engineer Johan August Brinell in 1900, it was the first widely used and standardized hardness test in engineering and metallurgy. The large size of indentation and possible damage to the test-piece limits its usefulness.

The typical test uses a 10mm diameter steel ball as an indenter with a 3,000 kilogram force (kgf) (29 kilonewtons; 6,600 pound force). For softer materials, a smaller force is used; for harder materials, a tungsten carbide ball is substituted for the steel ball. The indentation is measured and hardness calculated as:

$$\text{BHN} = \frac{2P}{\pi D (D - \sqrt{D^2 - d^2})}$$

where

P = applied force (kgf)

D = diameter of indenter (mm)

d = diameter of indentation (mm)

The BHN can be converted into the UTS, although the relationship is dependent on the material, and therefore determined empirically. The relationship is based on Meyer’s index (n) from Meyer’s law. If Meyer’s index is less than 2.2 then the ratio of UTS to BHN is 0.36. If Meyer’s index is greater than 2.2, then the ratio increases.

BHN is designated by the most commonly used test standards ASTM E10-08 and ISO 6506–1:2005 as HBW (H from hardness, B from brinell and W from the material of the indenter, tungsten carbide). In former standards HB or HBS were used to refer to measurements made with steel indenters.

HBW is calculated in both standards using the SI units as

$$\text{HBW} = 0.102 \frac{2F}{\pi D (D - \sqrt{D^2 - d^2})}$$

where

F = applied force (N)

D = diameter of indenter (mm)

d = diameter of indentation (mm)

Video 19. Brinell hardness test

<http://www.bing.com/videos/search?q=brinell+hardness+test&view=detail&mid=2B19FF115641A8484E512B19FF115641A8484E51&first=0>

Rockwell Hardness Test

The following is taken from Instron, "Rockwell Hardness Test."

Stanley P. Rockwell invented the Rockwell hardness test. He was a metallurgist for a large ball bearing company and he wanted a fast, non-destructive way to determine if the heat treatment process they were doing on the bearing races was successful. The only hardness tests he had available at the time were Vickers, Brinell and Scleroscope. The Vickers test was too time consuming, Brinell indents were too big for his parts, and the Scleroscope was difficult to use, especially on his smaller parts.

To satisfy his needs he invented the Rockwell test method. This simple sequence of test force application proved to be a major advance in the world of hardness testing. It enabled the user to perform an accurate hardness test on a variety of sized parts in just a few seconds.

Rockwell test methods are defined in the following standards:

- ASTM E18 Metals
- ISO 6508 Metals
- ASTM D785 Plastics

There are two types of Rockwell tests:

1. Rockwell: the minor load is 10 kgf, the major load is 60, 100, or 150 kgf.
2. Superficial Rockwell: the minor load is 3 kgf and major loads are 15, 30, or 45 kgf.

In both tests, the indenter may be either a diamond cone or steel ball, depending upon the characteristics of the material being tested.

ROCKWELL SCALES

Rockwell hardness values are expressed as a combination of a hardness number and a scale symbol representing the indenter and the minor and major loads. The hardness number is expressed by the symbol HR and the scale designation.

There are 30 different scales. The majority of applications are covered by the Rockwell C and B scales for testing steel, brass, and other metals. However, the increasing use of materials other than steel and brass as well as thin materials necessitates a basic knowledge of the factors that must be considered in choosing the correct scale to ensure an accurate Rockwell test. The choice is not only between the regular hardness test and superficial hardness test, with three different major loads for each, but also between the diamond indenter and the 1/16, 1/8, 1/4 and 1/2 in. diameter steel ball indenters.

If no specification exists or there is doubt about the suitability of the specified scale, an analysis should be made of the following factors that control scale selection:

- Type of material
- Specimen thickness
- Test location
- Scale limitations

PRINCIPAL OF THE ROCKWELL TEST

1. Select image to enlarge. The indenter moves down into position on the part surface.
2. A minor load is applied and a zero reference position is established.
3. The major load is applied for a specified time period (dwell time) beyond zero.

4. The major load is released leaving the minor load applied.

The resulting Rockwell number represents the difference in depth from the zero reference position as a result of the application of the major load.

Video 20. Rockwell hardness test

http://wn.com/Rockwell_hardness_test#videos

V-Notch Test

The following is taken from Wikipedia, “Charpy Impact Test.”

The Charpy impact test, also known as the Charpy v-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material’s toughness and acts as a tool to study temperature-dependent ductile-brittle transition. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. A major disadvantage is that all results are only comparative.

The test was developed in 1905 by French scientist Georges Charpy. It was pivotal in understanding the fracture problems of ships during WWII. Today it is used in many industries for testing materials used in the construction of pressure vessels and bridges and to determine how storms will affect materials used in them.

The apparatus consists of a pendulum axe swinging at a notched sample of material. The energy transferred to the material can be inferred by comparing the difference in the height of the hammer before and after a big fracture.

The notch in the sample affects the results of the impact test, thus it is necessary for the notch to be of regular dimensions and geometry. The size of the sample can also affect results, since the dimensions determine whether or not the material is in plane strain. This difference can greatly affect conclusions made.

The standard methods for notched bar impact testing of metallic materials can be found in ASTM E23, ISO 148-1, or EN 10045-1, where all the aspects of the test and equipment used are described in detail.

Video 21. V-notch test

<http://www.bing.com/videos/search?q=V-notch+test&view=detail&mid=75C9404662222383CB2875C9404662222383CB28&first=0>

Drop Weight Test

The following is taken from Westmoreland Mechanical Testing and Research, “Drop Weight Test.”

The drop-weight test consists of beam specimens prepared according to ASTM E208 specifications to initiate a material crack in a selected area of their tensile surfaces at the start of the test. During the test a series of specimens is subjected to a single impact load at a progression of selected temperatures to determine the maximum temperature at which a specimen breaks. The impact load is delivered by a guided, free-falling weight with an energy of 250 to 1200 ft-lb according to the yield strength of the steel to be tested. A stop is employed to prevent deflection of more than a few tenths of an inch.

After the specimen is prepared properly for the crack initiation, and conditioned to the proper temperature, the test begins. The initial test is conducted at a temperature estimated to be near the NDT temperature. The remaining specimens are then tested at a progression of temperature intervals to determine the break and no-break performance temperatures within 10°F.

Tension Test

The following is taken from Instron, “Tension Test.”

A tensile test, also known as tension test, is probably the most fundamental type of mechanical test performed on material. Tensile tests are simple, relatively inexpensive, and fully standardized. By pulling on something, one can very quickly determine how the material will react to forces being applied in tension. As the material is being pulled, its strength, along with how much it will elongate, can be determined.

If the material is pulled until it breaks, a curve will result showing how it reacted to the forces being applied. The point of failure is of much interest and is typically called its UTS.

Video 22. Tension test

<http://vimeo.com/1984472>

Fatigue Test

The following is taken from Instron, “Fatigue Test.”

A method for determining the behavior of materials under fluctuating loads. A specified mean load (which may be zero) and an alternating load are applied to a specimen and the number of cycles required to produce failure (fatigue life) is recorded. Generally, the test is repeated with identical specimens and various fluctuating loads. Loads may be applied axially, in torsion, or in flexure. Depending on amplitude of the mean and cyclic load, net stress in the specimen may be in one direction through the loading cycle, or may reverse direction. Data from fatigue testing often are presented in an S-N diagram, which is a plot of the number of cycles required to cause failure in a specimen against the amplitude of the cyclical stress developed. The cyclical stress represented may be stress amplitude, maximum stress, or minimum stress. Each curve in the diagram represents a constant mean stress. Most fatigue tests are conducted in flexure, rotating beam, or vibratory type machines.

Creep Test

The following is taken from Westmoreland Mechanical Testing and Research, “What is a Creep Test.”

Creep is high temperature progressive deformation at constant stress. High temperature is a relative term dependent on the materials involved. Creep rates are used in evaluating materials for boilers, gas turbines, jet engines, ovens, or any application that involves high temperatures under load. Understanding high temperature behavior of metals is useful in designing failure resistant systems.

A creep test involves a tensile specimen under a constant load maintained at a constant temperature. Measurements of strain are then recorded over a period of time.

Creep occurs in three stages: primary, or stage I; secondary, or stage II; and tertiary, or Stage III. stage I, or primary creep occurs at the beginning of the tests, and creep is mostly transient, not at a steady rate. Resistance to creep increases until stage II is reached. In stage II, or

secondary creep, the rate of creep becomes roughly steady. This stage is often referred to as steady state creep. In stage III, or tertiary creep, the creep rate begins to accelerate as the cross sectional area of the specimen decreases due to necking or internal voiding decreases the effective area of the specimen. If stage III is allowed to proceed, fracture will occur.

The creep test is usually employed to determine the minimum creep rate in stage II. Engineers need to account for this expected deformation when designing systems.

Corrosion Test

The following is taken from Corrosion Doctors, “Corrosion Testing.”

Test programs can provide useful information for a variety of tasks such as the development of new materials and coatings and the choice of protective schemes for new and old equipment. Test methods for determining corrosion resistance are specific and must be based on conditions prevailing in certain environments and applications. A large number of factors affect corrosion behavior; therefore, there is no universal corrosion test. The most reliable indication of corrosion behavior is service history. However, that information is rarely available exactly as needed, and therefore other tests are required, ranging from simple field trials to highly accelerated laboratory tests. It is the need to obtain information outside of service history that introduces ambiguity in corrosion testing.

To quantify the corrosion resistance of a material, it is common practice to submit the material to harsher environments than normally encountered in service, hoping to accelerate the damage. Alternatively, a corroded surface and the corrosion products formed during normal exposure can be studied with very sensitive surface analysis techniques, hoping to amplify the visibility and characteristics of the damage. Since most corrosion processes occur at the metal/environment interface, much progress in the study of corrosion mechanisms can be related to the gigantic advances made in surface analysis techniques. In fact, scientists involved in the study of fundamental processes of corrosion have often been the first to explore the application of new surface analysis techniques to materials engineering problems.

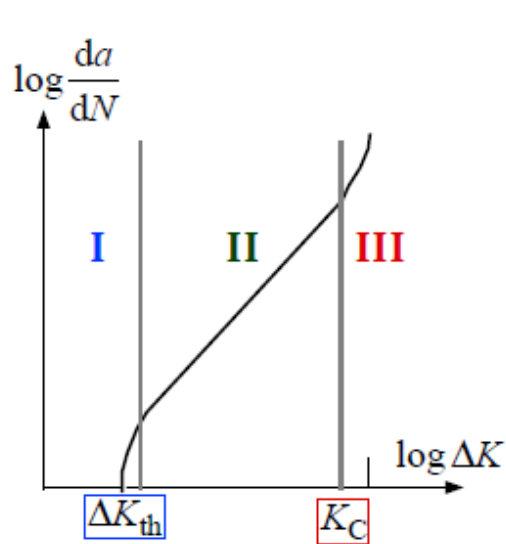
Alternate wet and dry cycles in the life of a system can create very serious corrosion problems mostly due to the formation of partially dry corrosion products that can further the accumulation of corrosive agents by absorption of moisture and the creation of under deposit corrosion. The severity of the corrosion attack created by alternate wetting and drying cycles can be used to accelerate corrosion and provide a relatively fast estimate of corrosion prevention measures. The ISO 11474 standard, for example, describes an accelerated outdoor corrosion test performed by intermittent spraying of a salt solution onto the exposed pieces of equipment or systems.

Crack Propagation Testing

The following is taken from Chalmers Solid Mechanics, “Fatigue Crack Propagation.”

In experiments, crack propagation has been measured as a function of the stress intensity factor.

There exists a threshold value of ΔK below which fatigue cracks will not propagate. At the other extreme, K_{\max} will approach the fracture toughness K_C , and the material will fail.



There is linear relationship between $\log (da/dN)$ and ΔK in region II.

Note that ΔK depends on the crack size. This is not shown in the plot.

For small ΔK (region I), crack propagation is difficult to predict since it depends on microstructure and flow properties of the material.

Here, the growth may even come to an arrest. Crack growth rate is sensitive to the size of the grains. Finer grains give

- closer spacing of grain boundaries, which the crack has to break through
- increased yield stress (normally)
- decreased roughness of the crack

Crack growth predicted by

- models of type $da/dN = f(\Delta\gamma_p)$, where $\Delta\gamma_p$ is plastic shear strain range
- empirical adjustment of $\Delta K - da/dN$ -curve

For larger magnitudes of ΔK (region II), the crack growth rate will be governed by a power law (such as Paris' law). The crack growth rate is fairly insensitive to the microstructure (however, the constants m and C are, of course, different for different materials)

If region II includes the dominating part of the fatigue life, the fatigue life can be directly estimated by integrating Paris' law.

If the stress intensity ratio is increased even further (region III), the crack growth rate will accelerate and finally fracture will occur

The behavior of this fracture is rather sensitive to the microstructure and flow properties of the material.

It has been found that, for dynamic loading of a crack, the three most important factors determining the propagation (growth) of the crack are

- $\Delta K = K_{\max} - K_{\min}$ – the stress intensity range
- $R = K_{\min}/K_{\max}$ – the stress intensity ratio
- H – the stress history

Thus, the crack growth rate (i.e. growth per stress cycle) can be expressed as

$$da/dN = f(\Delta K, R, H)$$

where da/dN is the crack growth per stress cycle.

d. Discuss the importance of traceability in nuclear system components.

The following is taken from National Institute of Standards and Technology, “Traceability.”

The definition of traceability that has achieved global acceptance in the metrology community is contained in the International vocabulary of metrology—Basic and general concepts and associated: “...property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.”

It is important to note that traceability is the property of the result of a measurement, not of an instrument or calibration report or laboratory. It is not achieved by following any one particular procedure or using special equipment. Merely having an instrument calibrated, even by NIST, is not enough to make the measurement result obtained from that instrument traceable to realizations of the appropriate SI unit or other specified references. The measurement system by which values and uncertainties are transferred must be clearly understood and under control.

6. Mechanical systems personnel shall demonstrate a working level knowledge of mechanical diagrams, including:

- **As-built drawings**
- **Piping and Instrumentation Diagrams (P&ID)**

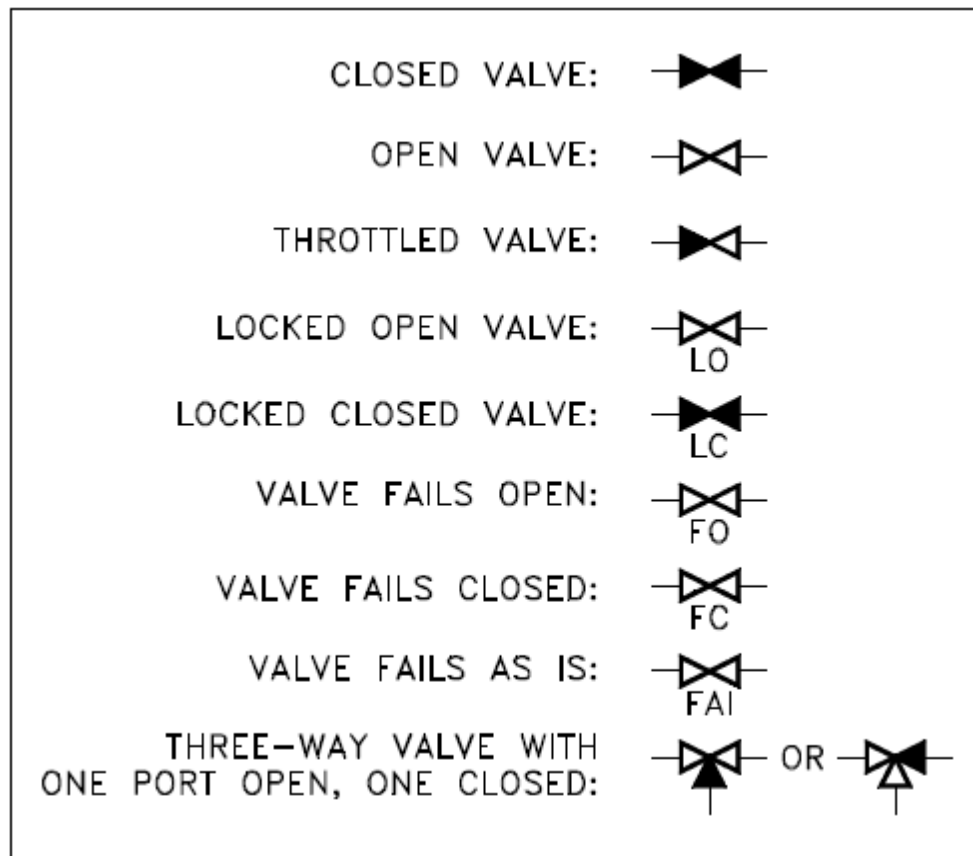
a. Identify the symbols used in P&IDs for the following types of items:

- **Valves**
- **Valve operators**
- **Eductors and ejectors**
- **Basic instrumentation**
- **Signal controllers and modifiers**
- **System components (pumps, etc.)**
- **Lines**

b. Identify the symbols used in P&IDs to denote the location of instruments, indicators, and controllers.

Elements a and b are performance based. The Qualifying Official will evaluate their completion.

c. Identify how valve positions are depicted.



Source: DOE-HDBK-1016/1-93

Figure 22. Valve conditions

d. Determine system flowpath(s) for a given valve lineup.

Element d is performance based. The Qualifying Official will evaluate its completion.

e. Discuss the origin and purpose of as-built drawings.

The following is taken from Wisegeek, “What are As-Built Drawings?”

As-built drawings are the final set of drawings produced at the completion of a construction project. They include all the changes that have been made to the original construction drawings, including notes, modifications, and any other information that the builder decides should be included. While the original drawings are typically produced using computer-aided design software, the as-built drawings usually contain handwritten notes, sketches, and changes.

To understand how as-built drawings are created, it is helpful to understand the process of developing construction drawings. The owner or developer of a project will hire an architect or engineer to design the proposed building. These design professionals will use the owner’s ideas and requirements to create construction drawings for the project. Once the owner has approved these plans, they are submitted to the local permitting agency to obtain building permits. This final set of plans is often known as the “permit set” or “100 percent construction drawings”.

Mandatory Performance Activities:

- Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity. The following information from DOE-HDBK-1016/1-93 may be helpful.

The title block of a drawing, usually located on the bottom or lower right hand corner, contains all the information necessary to identify the drawing and to verify its validity. A title block is divided into several areas, as illustrated by figure 23.

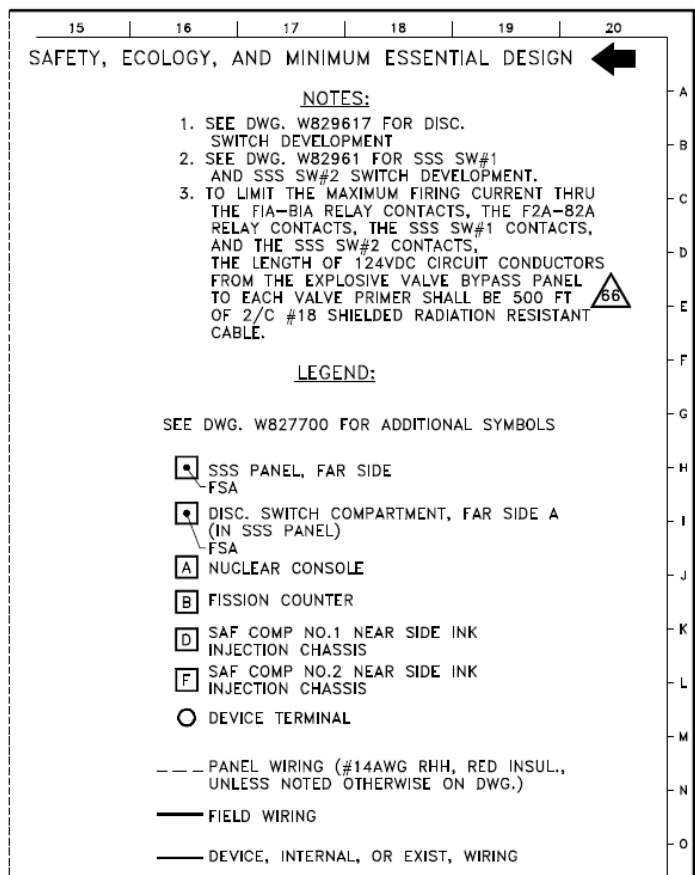
					UNITED STATES DEPARTMENT OF ENERGY			
					SAVANNAH RIVER SITE		PROCESS	TRACKING NO.
					BLDG. NO. 108-1K	PROBLEM NO. 1-5907	SITE CLEARANCE NO.	PROJECT NO. (EWR 86-6168)
					TITLE CCR DRAWING PIPING & INSTRUMENT DIAGRAM PROCESS WATER K - REACTOR COOLING WATER SYSTEM DIESEL GENERATOR		PREPARED BY: <i>J. Thomson</i>	
							CHECKED BY: <i>H. Donaldson</i>	
							DISCIPLINE ENGINEERING MANAGER: <i>L. Smith</i>	
							MANAGER PROJECT ENGINEERING: <i>Robert Anderson</i>	
							PHEM RELEASE: N/A	DATE:
							DESIGN RELEASE: N/A	DATE:
							CONSTRUCTION RELEASE: N/A	DATE:
							OPERATIONAL RELEASE: <i>B. Simpson</i>	DATE: 10/25/89
							FABRICATION RELEASE: N/A	DATE:
					DATE ISSUED: 10/25/89	SCALE: NONE	FILE:	
							SRG DRAWING NO. S5-1-9850	
					PLOT DATE 10/25/89		TIME:	
							LAST REV. 0	

Figure 23. Title block

Drawings are usually filed by their drawing number because the drawing title may be common to several prints or series of prints.

SECOND AREA OF THE TITLE BLOCK

The second area of the title block contains the signatures and approval dates, which provide information as to when and by whom the component/system was designed and when and by whom the drawing was drafted and verified for final approval. This information can be invaluable in locating further data on the system/component design or operation. These names can also help in the resolution of a discrepancy between the drawing and another source of information.



DOE-HDBK-1016/1-93

Figure 24. Notes and legend

and legends section of a drawing lists and explains any special symbols and conventions used on the drawing, as illustrated in figure 24. Also listed in the notes section is any information the designer or draftsman felt was necessary to correctly use or understand the drawing. Because of the importance of understanding all of the symbols and conventions used on a drawing, the notes and legend section must be reviewed before reading a drawing.

Revision Block

As changes to a component or system are made, the drawings depicting the component or system must be redrafted and reissued. When a drawing is first issued, it is called revision zero, and the revision block is empty. As each revision is made to the drawing, an entry is placed in the revision block. This entry provides the revision number, a title or summary of the revision, and the date of the revision. The revision number may also appear at the end of the drawing number or in its own separate block. As the component or system is modified, and the drawing

THIRD AREA OF THE TITLE BLOCK

The third area of the title block is the reference block. It lists other drawings that are related to the system/component, or it can list all the other drawings that are cross-referenced on the drawing, depending on the site's or vendor's conventions. The reference block can be extremely helpful in tracking down additional information on the system or component. Other information may also be contained in the title block and will vary from site to site and vendor to vendor. Some examples of other information are contract numbers and drawing scale.

Notes and Legend

Drawings are made up of symbols and lines that represent components or systems. Although a majority of the symbols and lines are self-explanatory or standard, a few unique symbols and conventions must be explained for each drawing. The notes

is updated to reflect the changes, the revision number is increased by one, and the revision number in the revision block is changed to indicate the new revision number. For example, if a revision 2 drawing is modified, the new drawing showing the latest modifications will have the same drawing number, but its revision level will be increased to 3. The old revision 2 drawing will be filed and maintained in the filing system for historical purposes.

Drawing Grid

Because drawings tend to be large and complex, finding a specific point or piece of equipment on a drawing can be quite difficult. This is especially true when one wire or pipe run is continued on a second drawing. To help locate a specific point on a referenced print, most drawings, especially P&ID and electrical schematic drawings, have a grid system. The grid can consist of letters, numbers, or both that run horizontally and vertically around the drawing. Like a city map, the drawing is divided into smaller blocks, each having a unique two-letter or two-number identifier. For example, when a pipe is continued from one drawing to another, not only is the second drawing referenced on the first drawing, but so are the grid coordinates locating the continued pipe. Therefore the search for the pipe contained in the block is much easier than searching the whole drawing.

- 7. Mechanical systems personnel shall demonstrate a working level knowledge of installed mechanical equipment.**
 - a. Discuss the function, required maintenance, and surveillance requirements (technical safety requirement [TSR] or good practice) for each type of component listed below.**

Refer to applicable manufacturers' manuals and local safety basis documents.

Mandatory Performance Activities:

- a. Given an as-built P&ID for a facility's fluid system, identify and physically locate in the facility the following components:**
 - Root valves
 - Flow control valves
 - Pumps
 - Pump motors
 - Speed increasers/decreasers
 - Steam traps
 - Filters
 - Sumps
 - Surge tanks
 - Reservoirs
 - Air compressors
 - Air dryers
 - Pneumatic valve operators
 - Electric valve operators
 - Hydraulic (if applicable) valve operators
 - Basic types of instrumentation (pressure, differential pressure, temperature, flow)
 - Supply lines
 - Return lines
 - Supply fans
 - Exhaust fans

- **Filter plenums**
- **Pressure differential gauges**
- **Dampers**
- **Air pre-heaters**
- **Air cooling coils**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity.

8. Mechanical systems personnel shall demonstrate a working level knowledge of a typical diesel generator, including support systems.

a. Differentiate between two-stroke and four-stroke (two-cycle and four-cycle) engines.

The following is taken from Deepscience, “Which is Better, a 2 Stroke or 4 Stroke Engine?”

Stroke refers to the movement of the piston in the engine. 2 Stroke means one stroke in each direction. A 2 stroke engine will have a compression stroke followed by an explosion of the compressed fuel. On the return stroke new fuel mixture is inserted into the cylinder.

A 4 stroke engine has 1 compression stroke and 1 exhaust stroke. Each is followed by a return stroke. The compression stroke compresses the fuel air mixture prior to the gas explosion. The exhaust stroke simply pushes the burnt gases out the exhaust.

A 4 stroke engine usually has a distributor that supplies a spark to the cylinder only when its piston is near TDC (top dead center) on the fuel compression stroke, i.e. one spark every two turns of the crank shaft. Some 4 stroke engines do away with the distributor and make sparks every turn of the crank. This means a spark happens in a cylinder that just has burnt gasses in it which just means the sparkplug wears out faster.

Video 23. Two-stroke and four-stroke engines

<http://videos.howstuffworks.com/autopinciple-com/4729-two-stroke-cycle-engine-video.htm>

b. Discuss the ignition principle of a diesel engine.

The following is taken from Wikipedia, “Diesel Engine.”

A diesel engine (also known as a compression-ignition engine) is an internal combustion engine that uses the heat of compression to initiate ignition to burn the fuel, which is injected into the combustion chamber. This is in contrast to spark-ignition engines such as a petrol engine (gasoline engine) or gas engine (using a gaseous fuel as opposed to gasoline), which use a spark plug to ignite an air-fuel mixture.

c. Discuss the purpose and principle of operation of a diesel engine injector.

The following is taken from Diesel Power Magazine, “Diesel Injector Nozzles.”

When discussing diesel engines, many people refer to the part that delivers fuel to the cylinder as an injector. To a true diesel expert, the injector is the nozzle holder assembly, but over time, it has been used to describe the actual nozzle. This has become complicated by the different fuel system designs that are employed on diesel engines. There are now mechanical unit injectors, electronic unit injectors, common-rail injectors, and hydraulically actuated electronic unit injectors that became popular with the introduction of the Ford Power Stroke engine.

To complicate matters, there are many different nozzle designs within the mechanical category that share operating characteristics in some instances. Hydraulic injectors are usually classified by the nozzle design. There are poppet, pintle, multi-orifice, and electro-hydraulic nozzle styles. Within each design category there are subsets of styles as well, such as those designed for indirect or direct injection applications. Regardless of the design, a mechanical injector that contains no electronic parts can and should be serviced. Electronically enhanced injectors in light-duty applications are traditionally not serviceable and need to be replaced as a unit.

Servicing Mechanical Injectors

There are three terms that should be understood that pertain to nozzle testing and service. They are nozzle opening pressure (NOP), back leakage, and forward leakage. An injector nozzle can be considered a hydraulic switch. One of its design elements is the pressure at which it opens. This is usually set with either a spring tension adjustment, or on some models, with shims. The term “pop-open pressure” is often used instead of nozzle opening pressure. Regardless of which term is used, it describes the amount of pressure that must be created by the injection pump before the nozzle will pass fuel into the cylinder. Each model of engine and nozzle design has its own NOP value that typically varies from 1,000 to 5,880 psi.

Some nozzles employ an internal opening valve that returns unused fuel to the tank. The internal leakage is a result of the nozzle-valve to nozzle-body clearance. It is measured during bench testing for ten seconds and recorded as back leakage.

Forward leakage is a nozzle’s ability to not drip or flow fuel until the NOP is reached. It confirms the nozzle’s ability to seal. To test for forward leakage, a pressure of approximately 150 psi below the NOP is created on the test bench. No visible dripping is allowed.

d. Discuss the purpose of the following diesel engine support systems:

- **Cooling water**
- **Lubrication**
- **Fuel oil**
- **Scavenging air**
- **Starting systems**

Cooling Water

The following is taken from Diesel Power Magazine, “Diesel Engine Cooling System.”

The purpose of the coolant (antifreeze or water) flowing through a diesel is to regulate the heat within the cylinder head and engine block that’s created by the combustion process. To accomplish that job the coolant must be pumped around the engine compartment, pick up heat from the engine, transfer that heat into the radiator, all while limiting corrosion, lubricating the water pump, and not freezing.

Traditional antifreeze is a mixture that is 50 percent mix of ethylene glycol (EG) and 50 percent water. There are also propylene-glycol-based (PG) products on the market, and they have some different but interesting performance characteristics when compared to EG.

If the proper coolant is not used, corrosion, overheating, or water-pump failure could occur in a diesel engine.

Both EG and PG fall into the glycols family that is much larger than the two formulations mentioned. Glycol is used in various forms not only as antifreeze but also in resin formulations,

plastics, solvents, fertilizer, food products, shaving cream, chemical production, and as an airplane deicer.

Lubrication

The following is taken from Diesel Power Magazine, “New Lubrication Standards for 2016 and Beyond.”

Most diesel enthusiasts know the 15W-40 oil they’ve traditionally put in their engines is thicker and has more viscosity than the 10W-30 or 5W-40 gasoline engines use. Fewer diesel fans have a complete grasp on the other symbols and numbers found on a bottle of oil.

American Petroleum Institute (API) was created during World War I to facilitate the United States’ war efforts. Today, this trade association of more than 400 corporate members has a mission to influence public policy in support of a strong, viable, international oil and gas industry. API also helps facilitate research and standards. Its engine oil licensing and certification system is a voluntary licensing and certification program that authorizes engine oil makers to use the API symbol of approval. In 2006, the CJ-4 category of diesel engine oils came online. The Engine Manufacturers Association (EMA) requested this oil category because they needed it for new emissions equipment such as EGR systems and exhaust after treatments. Today, a new oil standard is being worked out, which is a harbinger of the engine changes to come. By looking at how the oil will be changed to fit the new standards, we’ll be able to deduce what future engine schemes might be.

PC-11: A CATEGORY DESIGNED FOR NEW ENGINE TECHNOLOGIES

PC-11 is a new diesel engine oil category currently under development that will be ready in 2016. The EMA says they need a new oil category because of the changes in engine technology designed to meet emissions reduction, renewable fuel introduction, and fuel economy standards. PC-11 oil will need to have improved:

Oxidation stability: Just like rust that attacks the outside of a truck, oxygen reactions are breaking down the oil inside of a diesel engine. If oil oxidizes too much, an acid is formed, which can cause engine corrosion. If it goes too far, the size of the oil molecules increases and since this is what determines viscosity, plugged oil filters and damage to areas with tight tolerances can occur. PC-11 enables greater biodiesel fuel compatibility and allows for higher engine oil temperatures (since oxidation increases with increased temperatures). The EMA is calling for engine oil temperatures to be 10 degrees hotter.

Aeration: This condition is what happens when air bubbles or foam form in the oil and is often caused by incorrect oil level. Too low and the sump will suck air with the oil, too high and the crankshaft will churn the oil in the sump into a froth. The other factor that puts air into the oil is engine speed. The bubbles associated with oil aeration can cause oil blockage to lash adjusters, journal bearings, and connecting rod bearings. It can also cause oil pump cavitation. Aeration can also cause horsepower losses and increased engine temperatures since the oil can no longer carry off as much heat. When the bubbles pop, a flammable gas that can ignite and further increase engine temperatures is produced. It is possible to conclude that future diesel engines will spin faster, so oil that is less susceptible to aeration is necessary.

Shear stability, scuffing, and adhesive wear protection: If two flat pieces of steel are covered with oil and then stuck together, when someone tries to pull them apart, there is a force that tries to hold them together. This thin layer of oil is also what keeps engine parts from wearing each

other down. If enough pressure is added, the oil shears, which means all the molecules get lined up and the protective layer is broken down. Adhesive wear indicates one engine part rubbed another and got hot enough to weld some of its material to the other piece. The EMA asked for oil more resistant to high-pressure forces. This indicates that future engines will be worked harder.

Data that supports performance increases: The final oil qualification the EMA asked for was data showing lower viscosity engine oils would be able to deliver the fuel economy benefits while not giving up any protection qualities compared to the traditional, thicker oils.

Fuel Oil

The following is taken from Wikipedia, “Diesel Fuel.”

Diesel fuel in general is any liquid fuel used in diesel engines. The most common is a specific fractional distillate of petroleum fuel oil, but alternatives that are not derived from petroleum, such as biodiesel, biomass to liquid or gas to liquid diesel, are increasingly being developed and adopted. To distinguish these types, petroleum-derived diesel is increasingly called petrodiesel. Ultra-low sulfur diesel (ULSD) is a standard for defining diesel fuel with substantially lowered sulfur contents. As of 2007, almost all diesel fuel available in the United States of America, Canada and Europe is the ULSD type.

Scavenging Air

The following is taken from Wikipedia, “Scavenging.”

In automotive usage, scavenging is the process of pushing exhausted gas-charge out of the cylinder and drawing in a fresh draught of air ready for the next cycle.

This process is essential in having a smooth-running internal combustion engine. Modifying the exhaust system can detract from the ideal scavenging effects, and reduce fuel efficiency and power if not properly planned out and executed.

To increase scavenging potential, the entire path from intake to tailpipe must be tuned in sync with each other. This will ensure that the air flow is never interrupted. The acceleration and deceleration of this exhaust gas is what will hinder the scavenging potential.

For example, fast flowing heads and a tunnel ram intake combined with a poorly planned camshaft and exhaust system will cause the air to slow down and speed up throughout its journey, thus reducing its scavenging potential. So, to increase scavenging potential, the air must maintain a positive linear acceleration curve.

There are three types of scavenging on the basis of the flow of air:

1. Direct or cross scavenging
2. Loop scavenging, using Schnuerle porting
3. Uniflow scavenging

Starter Systems

The following is taken from Wikipedia, “Air-Start System.”

An air-start system is a power source used to provide the initial rotation to start large diesel and gas turbine engines.

Compared to a gasoline engine, diesel engines have very high compression ratios to provide for reliable and complete ignition of the fuel without spark plugs. An electric starter powerful

enough to turn a large diesel engine would itself be so large as to be impractical; thus, there is a need for an alternative system. When starting the engine, compressed air is admitted to whichever cylinder has a piston just over top dead center, forcing it downward. As the engine starts to turn, the air-start valve on the next cylinder in line opens to continue the rotation. As this goes on, fuel is injected into the cylinders, the engine is then under way and the air is cut off. To further complicate matters, a large engine is usually blown over first with zero fuel settings and the indicator cocks open, to prove that the engine is clear of any water build up and that everything is free to turn. After a successful blow ahead and a blow astern, the indicator cocks are closed on all the cylinders, and then the engine can be started on fuel. Significant complexity is added to the engine by using an air-start system, as the cylinder head must have an extra valve in each cylinder to admit the air in for starting, plus the required control systems. This added complexity and cost limits the use of air-starters to very large and expensive reciprocating engines.

Another method of air-starting an internal combustion engine is the use of compressed air or gas to drive a fluid motor in place of an electric motor. They can be used to start engines from 5 to 320 liters in size and if more starting power is necessary two or more motors can be used. Starters of this type are used in place of electric motors because of their lighter weight and higher reliability. They can also outlast an electric starter by a factor of three and are easier to rebuild.

An air-starter on a turbine engine would typically consist of a radial inward flow turbine, or axial flow turbine, which is connected to the high pressure compressor spool through the accessory gearbox, plus the associated piping and valves. Compressed air is provided to the system by bleed air from the aircraft's auxiliary power unit or from an air compressor mounted on ground support equipment.

Compared to electric starters, air-starters have a higher power-to-weight ratio. Electric starters and their wiring can become excessively hot if it takes longer than expected to start the engine, while air-starters can be run as long as their air supply lasts. Turbine starters are much simpler and are a natural fit for turbine engines, and thus are used extensively on large turbofan engines used on commercial and military aircraft.

e. Discuss the function, required maintenance, and surveillance requirements (TSR or good practice) for each of the following components:

- Diesel engine
- Electrical generator
- Fuel tank
- Day tank (if applicable)
- Starting system (air or battery)
- Fuel transfer pump(s)

Diesel Engine

The following is taken from the New World Encyclopedia, "Diesel Engine."

The diesel engine is an internal combustion engine that uses compression ignition, in which fuel ignites as it is injected into air in the combustion chamber that has been compressed to temperatures high enough to cause ignition. By contrast, petrol engines use the Otto cycle in which fuel and air are typically mixed before entering the combustion chamber and ignited by a spark plug, making compression ignition undesirable (engine knocking).

Compressing any gas raises its temperature, the method by which fuel is ignited in diesel engines. Air is drawn into the cylinders and is compressed by the pistons at compression ratios as high as 25:1, much higher than used for spark-ignite engines. At near the end of the compression stroke, diesel fuel is injected into the combustion chamber through an injector (or atomizer). The fuel ignites from contact with the air that, due to compression, has been heated to a temperature of about 1300–1650°F). The resulting combustion causes increased heat and expansion in the cylinder which increases pressure and moves the piston downward. A connecting rod transmits this motion to a crankshaft to convert linear motion to rotary motion for use as power in a variety of applications. Intake-air to the engine is usually controlled by mechanical valves in the cylinder head. For increased power output, most modern diesel engines are equipped with a turbocharger, and in some derivatives, a supercharger to increase intake air volume. Use of an aftercooler/intercooler to cool intake air that has been compressed, and thus heated, by the turbocharger increases the density of the air and typically leads to power and efficiency improvements.

In cold weather, diesel engines can be difficult to start because the cold metal of the cylinder block and head draw out the heat created in the cylinder during the compression stroke, thus preventing ignition. Some diesel engines use small electric heaters called glow plugs inside the cylinder help ignite fuel when starting. Some even use resistive grid heaters in the intake manifold to warm the inlet air until the engine reaches operating temperature. Engine block heaters connected to the utility grid are often used when an engine is turned off for extended periods (more than an hour) in cold weather to reduce startup time and engine wear. Diesel fuel is also prone to waxing in cold weather, a term for the solidification of diesel oil into a crystalline state. The crystals build up in the fuel line, eventually starving the engine of fuel. Low-output electric heaters in fuel tanks and around fuel lines are used to solve this problem. Also, most engines have a spill return system, by which any excess fuel from the injector pump and injectors is returned to the fuel tank. Once the engine has warmed, returning warm fuel prevents waxing in the tank. Fuel technology has improved recently so that with special additives waxing only occurs in the coldest climates.

A vital component of all diesel engines is a mechanical or electronic governor, which limits the speed of the engine by controlling the rate of fuel delivery. Unlike Otto cycle engines, incoming air is not throttled and a diesel engine without a governor can easily overspeed. Mechanically governed fuel injection systems are driven by the engine's gear train. These systems use a combination of springs and weights to control fuel delivery relative to both load and speed. Modern, electronically controlled, diesel engines control fuel delivery and limit the maximum (rpm) by use of an electronic control module (ECM) or electronic control unit (ECU). The ECM/ECU receives an engine speed signal from a sensor and controls the amount of fuel and start of injection timing through electric or hydraulic actuators.

Controlling the timing of the start of injection of fuel into the cylinder is a key to minimizing emissions, and maximizing fuel economy (efficiency), of the engine. The timing is usually measured in units of crank angle of the piston before top dead center (TDC). For example, if the ECM/ECU initiates fuel injection when the piston is 10 degrees before TDC, the start of injection, or timing, is said to be 10 deg BTDC. Optimal timing will depend on the engine design as well as its speed and load.

Advancing the start of injection results in higher in-cylinder pressure and temperature, and higher efficiency, but also results in higher emissions of oxides of nitrogen through higher

combustion temperatures. At the other extreme, delayed start of injection causes incomplete combustion and emits visible black smoke made of particulate matter and unburned hydrocarbon.

Video 24. The diesel engine

<http://www.bing.com/videos/search?q=diesel+engine&view=detail&mid=793573DB9C7371CBB3C1793573DB9C7371CBB3C1&first=101>

Electrical Generator

The following is taken from Wikipedia, “Electric Generator.”

In electricity generation, an electric generator is a device that converts mechanical energy to electrical energy. A generator forces electric charge to flow through an external electrical circuit. It is analogous to a water pump, which causes water to flow. The source of mechanical energy may be a reciprocating or turbine steam engine, water falling through a turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, compressed air, or any other source of mechanical energy.

The reverse conversion of electrical energy into mechanical energy is done by an electric motor, and motors and generators have many similarities. Many motors can be mechanically driven to generate electricity, and frequently make acceptable generators.

Video 25. Simple electrical generator

<http://www.bing.com/videos/search?q=electrical+generator&view=detail&mid=990B58296C25F22AB097990B58296C25F22AB097&first=0>

Fuel Tank

The following is taken from Wikipedia, “Fuel Tank.”

A petrol fuel tank is a safe container for flammable fluids. Though any storage tank for fuel may be so called, the term is typically applied to part of an engine system in which the fuel is stored and propelled or released into an engine. Fuel tanks range in size and complexity from the small plastic tank of a butane lighter to the multi-chambered cryogenic Space Shuttle external tank.

Typically, a fuel tank must allow or provide the following:

- Storage of fuel: the system must contain a given quantity of fuel and must avoid leakage and limit evaporative emissions
- Filling: the fuel tank must be filled in a secure way, without sparks
- Provide a method for determining level of fuel in tank, gauging (the remaining quantity of fuel in the tank must be measured or evaluated)
- Venting (if over-pressure is not allowed, the fuel vapors must be managed through valves)
- Feeding of the engine (through a pump)
- Anticipate potentials for damage and provide safe survival potential.

Plastic (high-density polyethylene HDPE) as a fuel tank material of construction, while functionally viable in the short term, has a long term potential to become saturated as fuels such as diesel and gasoline permeate the HDPE material.

Considering the inertia and kinetic energy of fuel in a plastic tank being transported by a vehicle, environmental stress cracking is a definite potential. The flammability of fuel makes

stress cracking a possible cause of catastrophic failure. Emergencies aside, HDPE plastic is suitable for short term storage of diesel and gasoline.

Day Tank

The following is taken from DayTank.com, “Day Tanks.”

Day tanks were originally specified as an above ground, local source of fuel for emergency and stand-by generator sets. These tanks were sized to automatically maintain 24 hours of fuel next to the generator set. As the industry grew, however, the term “day tank” became synonymous with any above ground tank that has a pump, motor and control circuitry mounted on top.

Starting System

The following is taken from Wikipedia, “Air-Start System.”

An air-start system is a power source used to provide the initial rotation to start large diesel and gas turbine engines.

Compared to a gasoline engine, diesel engines have very high compression ratios to provide for reliable and complete ignition of the fuel without spark plugs. An electric starter powerful enough to turn a large diesel engine would itself be so large as to be impractical; so an alternative system is needed. When starting the engine, compressed air is admitted to whichever cylinder has a piston just over top dead center, forcing it downward. As the engine starts to turn, the air-start valve on the next cylinder in line opens to continue the rotation. As this goes on, fuel is injected into the cylinders, the engine is then under way and the air is cut off. To further complicate matters, a large engine is usually blown over first with zero fuel settings and the indicator cocks open, to prove that the engine is clear of any water build up and that everything is free to turn. After a successful blow ahead and a blow astern, the indicator cocks are closed on all the cylinders, and then the engine can be started on fuel. Significant complexity is added to the engine by using an air-start system, as the cylinder head must have an extra valve in each cylinder to admit the air in for starting, plus the required control systems. This added complexity and cost limits the use of air-starters to very large and expensive reciprocating engines.

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Fuel Transfer Pump

The following is taken from CarTech Auto Parts, “Fuel Transfer Pump.”

A fuel transfer pump is essential when there is an auxiliary tank because that is the device that will transfer the fuel from an auxiliary tank into a main fuel tank. An electric fuel transfer pump supply line is normally connected from the auxiliary tank to the vent hose of the main tank when a fuel transfer tank is installed. Once the main tank is empty, the operator can turn on the fuel transfer pump or have a set up that does it automatically.

Some people would rather have an electric fuel transfer pump than a switch valve. When they have an auxiliary tank an electric transfer pump will make things a lot easier. It will also be more reliable than using a switch valve to get the fuel from the auxiliary tank. Some of the better electric fuel transfer pump systems have a control panel. They typically have a digital readout. The amount of fuel in each tank will be shown and the fuel transfer is done automatically whenever it is needed. Both tanks are labeled on the control panel as main and auxiliary. The whole system is set up so that the fuel gauge registers how much fuel is in the auxiliary tank too.

When the fuel switch is on main, the fuel in the main tank is used. When it is on auxiliary, the fuel in that tank is used.

There are different types of fuel transfer pumps. Some are used to transfer large amounts of fuel for certain companies that use a lot of it in their daily business operations.

Mandatory Performance Activities:

- a. **Given an as-built P&ID for a facility’s diesel generator system, identify and physically locate in the facility the above components.**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity. Applicable manufacturers’ manuals and local safety basis documents should be used as references.

9. **Mechanical systems personnel shall demonstrate a working level knowledge of the construction and operation of heat exchangers.**

- a. **Describe the principle of operation for the following types of heat exchangers:**
 - **Shell and tube**
 - **Fin and tube**
 - **Cooling tower**

Video 26. Heat exchanger

<http://www.bing.com/videos/search?q=shell+and+tube+heat+exchanger&view=detail&mid=E776C3CFD09AF88F56E1E776C3CFD09AF88F56E1&first=0>

Shell and Tube

The following is taken from Wikipedia, “Shell and Tube Heat Exchanger.”

A shell and tube heat exchanger is a class of heat exchanger designs. It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consists of a shell with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over

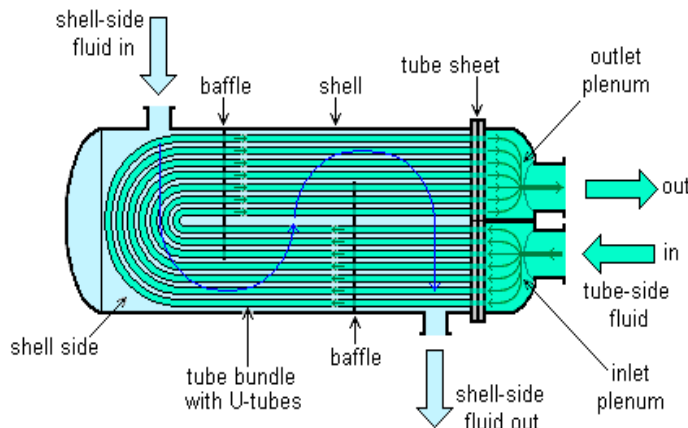
the tubes to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc.

Two fluids, of different starting temperatures, flow through the heat exchanger. One flows through the tubes and the other flows outside the tubes but inside the shell. Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. To transfer heat efficiently, a large heat transfer area should be used, leading to the use of many tubes. In

this way, waste heat can be put to use. This is an efficient way to conserve energy.

Heat exchangers with only one phase on each side can be called one-phase or single-phase heat exchangers.

Two-phase heat exchangers can be used to heat a liquid to boil it into a gas (these exchangers are sometimes called boilers) or cool a vapor to condense it into a liquid (these exchangers are called condensers) with the phase change usually occurring on the shell side. In large power plants with steam-driven turbines, shell-and-tube surface

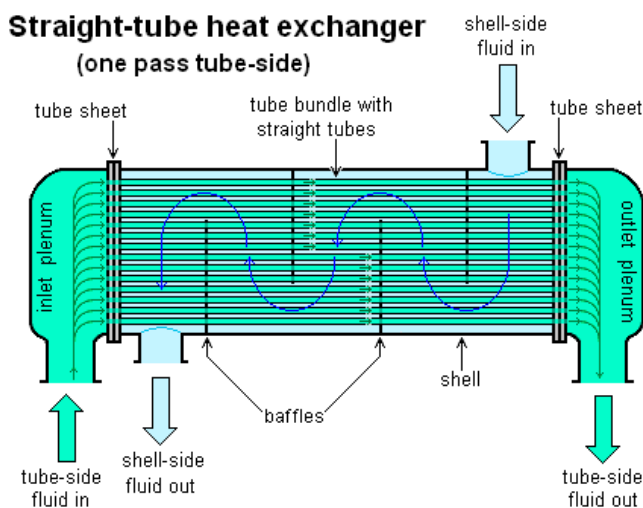


Source: Wikipedia, Shell and Tube Heat Exchangers

Figure 25. U-tube heat exchanger

condensers are used to condense the exhaust steam exiting the turbine into condensate water that is recycled back and turned into steam in the steam generator.

There can be many variations on the shell and tube design. Typically, the ends of each tube are connected to plenums through holes in tubesheets. The tubes may be straight or bent in the shape of a U, called U-tubes (See figure 25).



Source: Wikipedia, Shell and Tube Heat Exchangers

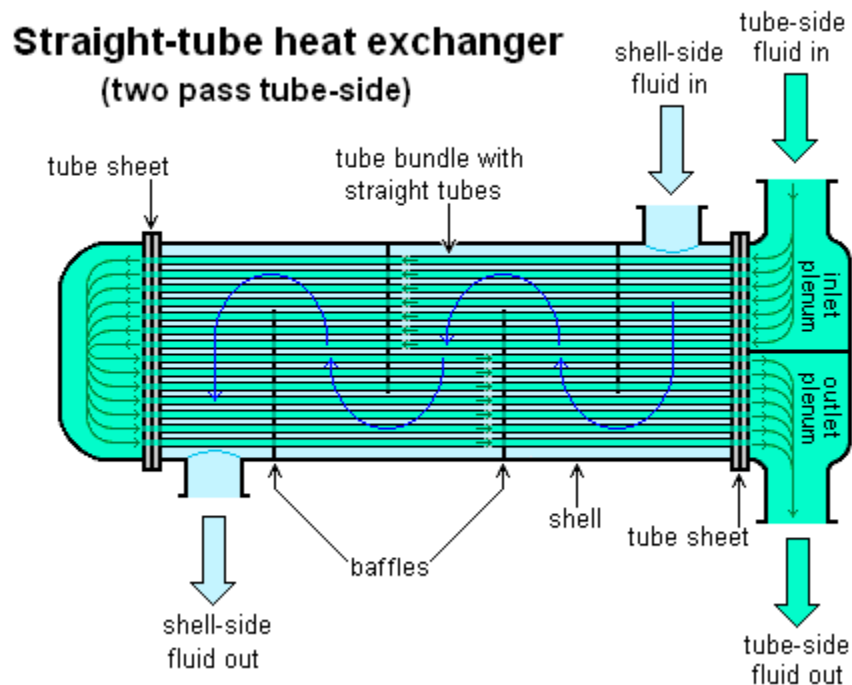
Figure 26. One pass tube-side

In nuclear power plants called pressurized water reactors, large heat exchangers called steam generators are two-phase, shell-and-tube heat exchangers which typically have U-tubes. They are used to boil water recycled from a surface condenser into steam to drive a turbine to produce power. Most shell-and-tube heat exchangers are 1, 2, or 4 pass designs on the tube side. This refers to the number of times the fluid in the tubes passes through the fluid in the shell. In a single pass heat exchanger, the fluid goes in one end of each tube and out the other.

Surface condensers in power plants are often 1-pass straight-tube heat exchangers (See figure 26). Two and four pass designs are common because the fluid can enter and exit on the same side. This makes construction much simpler. An illustration of a two pass design is in figure 27.

There are often baffles directing flow through the shell side so the fluid does not take a short cut through the shell side leaving ineffective low flow volumes. These are generally attached to the tube bundle rather than the shell so that the bundle is still removable for maintenance.

Counter current heat exchangers are most efficient because they allow the highest log mean temperature difference between the hot and cold streams. Many companies, however, do not use single pass heat exchangers because they can break easily in addition to being more expensive to build. Often multiple heat exchangers can be used to simulate the counter current flow of a single large exchanger.



Source: Wikipedia, Shell and Tube Heat Exchangers

Figure 27. Two pass tube-side

Fin and Tube

The following is taken from Wikipedia, "Plate Fin Heat Exchanger."

This type of heat exchanger uses sandwiched passages containing fins to increase the effectiveness of the unit. The designs include crossflow and counterflow coupled with various fin configurations such as straight fins, offset fins, and wavy fins.

Plate and fin heat exchangers are usually made of aluminum alloys that provide higher heat transfer efficiency. The material enables the system to operate at a lower temperature and reduces the weight of the equipment. Plate and fin heat exchangers are mostly used for low temperature services such as natural gas, helium, and oxygen liquefaction plants, air separation plants, and transport industries such as motor and aircraft engines.

Advantages of plate and fin heat exchangers

- high heat transfer efficiency especially in gas treatment
- larger heat transfer area
- approximately 5 times lighter in weight than that of shell and tube heat exchanger
- able to withstand high pressure

Disadvantages of plate and fin heat exchangers

- might cause clogging as the pathways are very narrow
- difficult to clean the pathways
- aluminum alloys are susceptible to mercury liquid embrittlement failure

Cooling Tower

The following is taken from the Cooling Technology Institute, “Cooling Towers.”

A cooling tower is a heat rejection device that extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature. The type of heat rejection in a cooling tower is termed evaporative in that it allows a small portion of the water being cooled to evaporate into a moving air stream to provide significant cooling to the rest of that water stream. The heat from the water stream transferred to the air stream raises the air's temperature and its relative humidity to 100 percent, and this air is discharged to the atmosphere. Evaporative heat rejection devices such as cooling towers are commonly used to provide significantly lower water temperatures than achievable with air-cooled or dry-heat rejection devices, like the radiator in a car, thereby achieving more cost-effective and energy efficient operation of systems in need of cooling.

Common applications for cooling towers are providing cooled water for air-conditioning, manufacturing, and electric power generation. The smallest cooling towers are designed to handle water streams of only a few gallons of water per minute supplied in small pipes like those in a residence, while the largest cool hundreds of thousands of gpm supplied in pipes as much as 15 feet in diameter on a large power plant.

The generic term “cooling tower” is used to describe direct and indirect heat rejection equipment. While most think of a cooling tower as an open, direct-contact, heat-rejection device, the indirect cooling tower, sometimes referred to as a closed-circuit cooling tower is nonetheless also a cooling tower.

A direct, or open-circuit cooling tower is an enclosed structure with internal means to distribute the warm water fed to it over a labyrinth-like packing or fill. The fill provides a vastly expanded air-water interface for heating of the air and evaporation to take place. The water is cooled as it descends through the fill by gravity while in direct contact with air that passes over it. The cooled water is then collected in a cold water basin below the fill from which it is pumped back through the process to absorb more heat. The heated and moisture laden air leaving the fill is discharged to the atmosphere at a point remote enough from the air inlets to prevent its being drawn back into the cooling tower.

The fill may consist of multiple, mainly vertical, wetted surfaces upon which a thin film of water spreads, or several levels of horizontal splash elements that create a cascade of many small droplets that have a large combined surface area.

An indirect, or closed circuit cooling tower involves no direct contact of the air and the fluid, usually water or a glycol mixture, being cooled. Unlike the open cooling tower, the indirect cooling tower has two separate fluid circuits. One is an external circuit in which water is recirculated on the outside of the second circuit, which is tube bundles that are connected to the process for the hot fluid being cooled and returned in a closed circuit. Air is drawn through the recirculating water cascading over the outside of the hot tubes, providing evaporative cooling similar to that of an open cooling tower. In operation the heat flows from the internal fluid circuit, through the tube walls of the coils, to the external circuit and then by heating of the air and evaporation of some of the water, to the atmosphere. Operation of the indirect cooling tower is therefore very similar to the open cooling tower with one exception. The process fluid being cooled is contained in a closed circuit and is not directly exposed to the atmosphere or the recirculated external water.

In a counter-flow cooling tower, air travels upward through the fill or tube bundles, opposite to the downward motion of the water. In a cross-flow cooling tower, air moves horizontally through the fill as the water moves downward.

Cooling towers are also characterized by the means by which air is moved. Mechanical-draft cooling towers rely on power-driven fans to draw or force the air through the tower. Natural-draft cooling towers use the buoyancy of the exhaust air rising in a tall chimney to provide the draft. A fan-assisted natural-draft cooling tower employs mechanical draft to augment the buoyancy effect. Many early cooling towers relied only on prevailing wind to generate the draft of air.

b. Define the following terms as they apply to heat exchangers:

- **Tube sheet**
- **Telltale drain**
- **Parallel flow**
- **Counterflow**
- **Cross-flow**

Tube Sheet

The following is taken from WiseGeek, “What is a Tube Sheet?”

A tube sheet is a plate, sheet, or bulkhead that is perforated with a pattern of holes designed to accept pipes or tubes. These sheets are used to support and isolate tubes in heat exchangers and boilers or to support filter elements. Depending on the application, a tube sheet may be made of various metals or of resin composites or plastic. A tube sheet may be covered in a cladding material that serves as a corrosion barrier and insulator and may also be fitted with a galvanic anode. Tube sheets may be used in pairs in heat exchange applications or singularly when supporting elements in a filter.

The best know use of tube sheets are as supporting elements in heat exchangers and boilers. These devices consist of a dense arrangement of thin walled tubes situated inside an enclosed, tubular shell. Tubes are supported on either end by sheets that are drilled in a predetermined pattern to allow the tube ends to pass through the sheet. The ends of the tubes that penetrate the tube sheet are expanded to lock them in place and to form a seal.

Video 27. Tube sheet production

<http://www.youtube.com/watch?v=Nez4ItWi3N8>

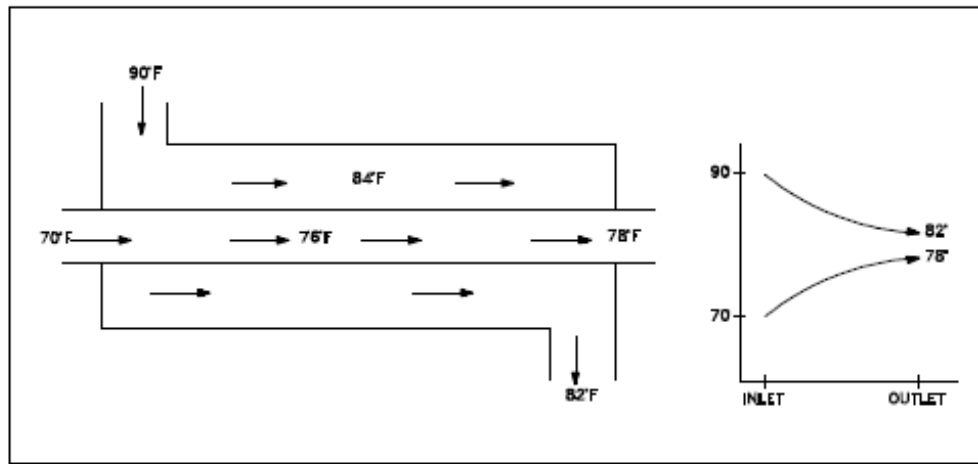
Telltale Drain

A telltale drain is a drain placed between the two parts of the tube sheet to indicate a leak in either the water box side or the process fluid side.

Parallel Flow

The following is taken from DOE-HDBK-1018/1-93.

Parallel flow, as illustrated in figure 28, exists when the tube side fluid and the shell side fluid flow in the same direction. In this case, two fluids with a large temperature difference enter the heat exchanger from the same end. As the fluids transfer heat, hotter to cooler, the temperatures of the two fluids approach each other. Note that the hottest cold-fluid temperature is always less than the coldest hot-fluid temperature.



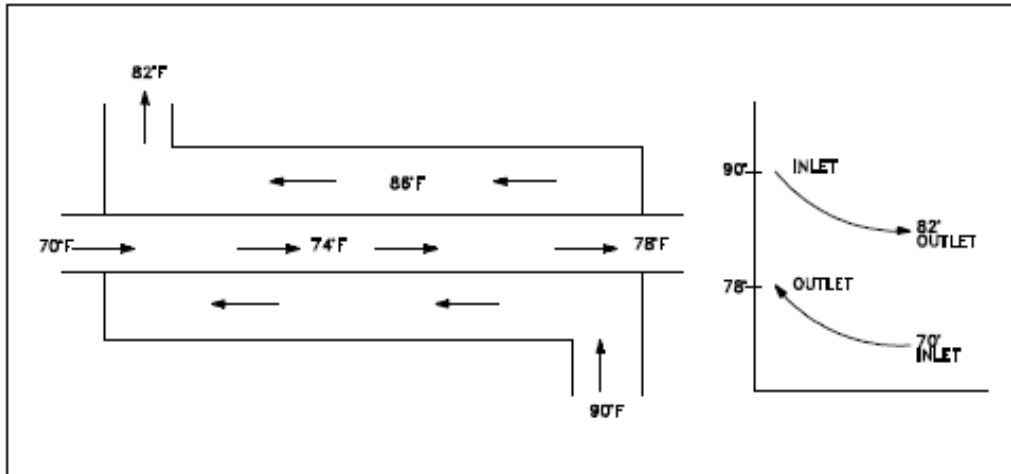
Source: DOE-HDBK-10018/1-93

Figure 28. Parallel flow heat exchanger

Counter Flow

The following is taken from DOE-HDBK-1018/1-93.

Counter flow, as illustrated in figure 29, exists when the two fluids flow in opposite directions. Each of the fluids enters the heat exchanger from opposite ends. Because the cooler fluid exits the counter flow heat exchanger at the end where the hot fluid enters the heat exchanger, the cooler fluid will approach the inlet temperature of the hot fluid. Counter flow heat exchangers are the most efficient of the three types. In contrast to the parallel flow heat exchanger, the counter flow heat exchanger can have the hottest cold-fluid temperature greater than the coldest hot-fluid temperature.



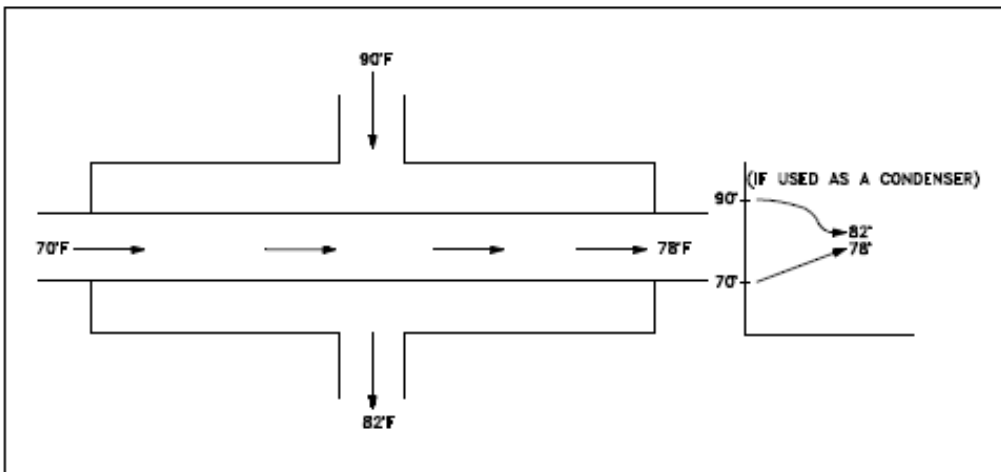
Source: DOE-HDBK-10018/1-93

Figure 29. Counter flow heat exchanger

Cross Flow

The following is taken from DOE-HDBK-1018/1-93.

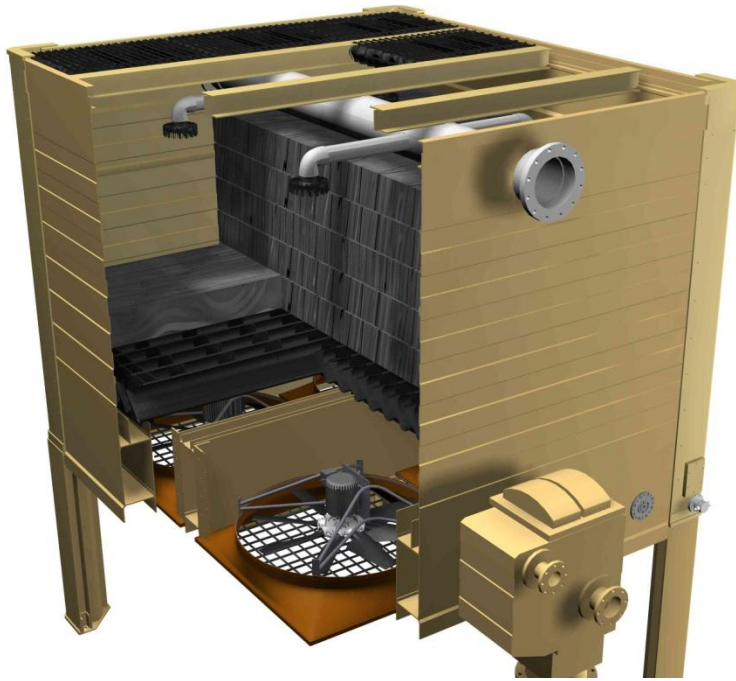
Cross flow, as illustrated in figure 30, exists when one fluid flows perpendicular to the second fluid; that is, one fluid flows through tubes and the second fluid passes around the tubes at a 90° angle. Cross flow heat exchangers are usually found in applications where one of the fluids changes state (2-phase flow). An example is a steam system's condenser, in which the steam entering the turbine enters the condenser shell side, and the cool water flowing in the tubes absorbs the heat from the steam, condensing it into water. Large volumes of vapor may be condensed using this type of heat exchanger flow.



Source: DOE-HDBK-1018/1-93

Figure 30. Cross flow heat exchanger

c. Explain the principle of operation of a forced-draft cooling tower.



Source: Tower Tech, Forced Draft Cooling Tower

Figure 31. Forced draft cooling tower

exhaust airstream. This makes the mechanical equipment difficult, expensive, time-intensive, and dangerous to maintain.

Forced draft cooling towers have the mechanical equipment at the bottom of the tower. This location allows the equipment to operate in the cool, dry, intake airstream protected from the elements. This location makes the equipment accessible from ground level so it is easy, inexpensive, less time consuming, and much safer to repair, while the mechanical equipment enjoys substantially increased life expectancy.

d. Explain the principle of operation of a natural convection (parabolic) cooling tower.

The following is taken from Wikipedia, “Natural Convection Cooling.”

Natural convection is a mechanism, or type of heat transport, in which the fluid motion is not generated by any external source (like a pump, fan, suction device, etc.) but only by density differences in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source receives heat, becomes less dense, and rises. The surrounding cooler fluid then moves to replace it. This cooler fluid is then heated and the process continues, forming a convection current; this process transfers heat energy from the bottom of the convection cell to top. The driving force for natural convection is buoyancy, a result of differences in fluid density. Because of this, the presence of a proper acceleration such as arises from resistance to gravity, or an equivalent force, is essential for natural convection. For example, natural convection essentially does not operate in a free-fall environment, such as that of the orbiting international space station, where other heat transfer mechanisms are required to prevent electronic components from overheating.

Forced draft cooling tower installations are becoming increasingly more popular. Cooling tower technology allows for a fan to be mounted on the top or bottom of a cooling tower. Cooling towers with top mounted fans are called “induced draft” cooling towers and cooling towers with bottom mounted fans are called “forced draft” cooling towers.

Induced draft cooling towers frequently employ a fan, coupling, gear box, drive shaft and motor at the top of the cooling tower. This equipment is used to induce air from the bottom air inlet louvers up through the fill media. This location accelerates wear and tear of the equipment because it is exposed to the elements (sun, rain, snow, etc.), and is positioned in the hot, corrosive,

Natural convection has attracted a great deal of attention from researchers because of its presence in nature and engineering applications. In nature, convection cells formed from air rising above sunlight-warmed land or water are a major feature of all weather systems. Convection is also seen in the rising plume of hot air from fire, oceanic currents, and sea-wind formation. In engineering applications, convection is commonly visualized in the formation of microstructures during the cooling of molten metal, and fluid flows around shrouded heat-dissipation fins, and solar ponds. A very common industrial application of natural convection is free air cooling without the aid of fans: this can happen on small scale to large scale process equipment.

Mandatory Performance Activities:

- a. **Given a cutaway drawing of the following types of heat exchangers, show the flow paths of the cooling medium and the medium to be cooled:**
 - **Parallel flow**
 - **Counter flow**
 - **Cross flow**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity.

10. Mechanical systems personnel shall demonstrate a working level knowledge of the theory and operation of heating, ventilation, and air conditioning (HVAC) systems.

- a. **Define the following terms as they apply to HVAC systems:**
 - **Latent heat of vaporization**
 - **Latent heat of fusion**
 - **Refrigerant**
 - **Vaporization point**
 - **Air and noncondensable gases**

Latent Heat of Vaporization

The following is taken from Aus-e-Tute, “Latent Heat.”

Latent heat of vaporization is the heat absorbed per mole when a substance changes state from liquid to gas at constant temperature.

Latent Heat of Fusion

The following is taken from Aus-e-Tute, “Latent Heat.”

Latent Heat of fusion is the heat absorbed per mole when a substance changes state from solid to liquid at constant temperature.

Refrigerant

The following is taken from New World Encyclopedia, “Refrigerant.”

A refrigerant is a substance that is used to provide cooling through a heat cycle in which the substance undergoes changes in phase from gas to liquid and back to gas. Refrigerants are used mainly for refrigerators, freezers, and air conditioners.

In early refrigeration systems, the refrigerants employed were sulfur dioxide or anhydrous ammonia gas. These were later replaced by chlorofluorocarbons (CFCs) under the trade names Freon and Arcton. However, based on the understanding that CFCs in the upper atmosphere

destroy the protective ozone layer, they are considered to be environmental hazards and are being replaced by alternative refrigerants.

The ideal refrigerant has good thermodynamic properties, is noncorrosive, and safe. The desired thermodynamic properties are a boiling point somewhat below the target temperature, a high heat of vaporization, a moderate density in liquid form, and a relatively high density in gaseous form. Since boiling point and gas density are affected by pressure, refrigerants may be made more suitable for a particular application by choice of operating pressure.

Corrosion properties are a matter of materials compatibility with the components used for the compressor, piping, evaporator, and condenser. Safety considerations include toxicity and flammability.

Vaporization Point

The following is taken from Wikipedia, “Vaporization.”

Vaporization of an element or compound is a phase transition from the liquid phase to gas phase. There are two types of vaporization: evaporation and boiling.

Figure 29 shows the nomenclature for the different phase transitions. Evaporation is a phase transition from the liquid phase to gas phase that occurs at temperatures below the boiling

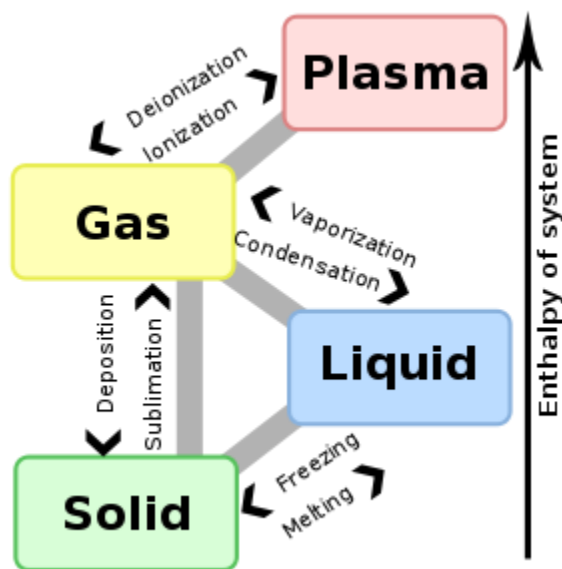
temperature at a given pressure.

Evaporation usually occurs on the surface.

Boiling is a phase transition from the liquid phase to gas phase that occurs at or above the boiling temperature. Boiling, as opposed to evaporation, occurs below the surface.

Sublimation is a direct phase transition from the solid phase to the gas phase, skipping the intermediate liquid phase.

The term vaporization has also been used to refer to the physical destruction of an object that is exposed to intense heat. As noted in discussions of the effects of nuclear weapons, this includes the vaporization of human bodies by the 1945 atomic bombings of Hiroshima and Nagasaki and the vaporization of the uninhabited Marshall Island of Elugelab in the 1952 Ivy Mike thermonuclear test.



Source: Wikipedia, Vaporization

Figure 32. Nomenclature for different phases

The best way to describe such a process is that a flux of so many gamma ray, x-ray, ultraviolet, and heat photons struck matter in a brief amount of time (photons of high energy and great numbers of them, some overlapping in the same physical space) that all such matter molecules lost their atomic bonds and “flew apart”, all atoms lost their bonds to each other and “flew apart”; and all nuclei lost their electron shells and became positively charged ions; and, each molecule and atom that followed this process in turn emitted photons of a slightly lower energy than they had absorbed which caused the bonds to break. All such matter became a gas of nuclei

and negatively charged electron ions that rose into the air due to their high temperature, or bonded to each other or to other matter as they cooled.

Video 28. Enthalpy of Vaporization

http://wn.com/enthalpy_of_vaporization#videos

Air and Noncondensable Gases

The following is taken from Plant Engineering, “Removal of Non-Condensable Gases, Air is Critical in a Steam System.”

Air and non-condensable gases are major problems in a steam system. Both can cause production problems for a steam system’s operation and performance. For example, the thermal conductivity of air is 0.000049, compared with 0.002 for water, 0.20 for iron, and 0.96 for copper. Not removing air and non-condensable gases from the steam system can reduce heat transfer efficiencies by 21 percent or more depending on the air concentration in the steam system. Because air is one of the greatest insulators, a major steam operation objective is elimination of air from a steam system.

Adding to the problem is the fact that steam systems are typically not designed to eliminate air at startup or during operation. During shutdown of a steam system or its components, the system depressurizes; the steam condensing and reducing in volume by as much as 1,600 times. This reduction in volume produces a vacuum in the steam system or steam components. Air is drawn into the steam system through steam components, such as air vents, valve packing, and flanges, and the air drawn in fills the vacuum. When energizing a steam system or steam heat transfer components, one of the first goals should be to vent the air out of the steam system or components.

WHERE DO NON-CONDENSABLE GASES AND AIR COME FROM?

Feedwater contains a small percentage of non-condensable gases in solution. When the boiler water changes state (liquid to vapor), the non-condensable gases are released and carried with the steam into the plant. Steam will release the latent energy to the process and condense down to condensate in the heat transfer area, but the non-condensable gases do not condense. These gases stay in the heat transfer component unless some method or action removes them.

During the steam system operation, the percentage of steam in the system will be close to 100 percent steam vapor with a small percentage of non-condensable gases.

When steam is shut down to the heat transfer unit or steam supply line for maintenance or process changes, the steam will condense and decrease in volume, which will open the vacuum breakers on the steam heat transfer unit, allowing air to flow into the system. It is extremely important to have functional vacuum breakers on the heat transfer unit to enable the condensate to drain out of the unit by gravity. If vacuum breakers are not on the heat transfer unit, the vacuum will hold the condensate in the unit and cause another set of issues. A steam line that does not have vacuum breakers will draw air in from components on the system (such as valve packing or flanges) and fill the void in the line.

HOW DOES AIR AFFECT THE SYSTEM?

Air reduces the heat transfer efficiency.

The release of latent energy (change of state) to condensate in the steam components takes place on the heat transfer surface, which is where heat is being transferred due to the temperature

difference (steam to the process). The steam component transfer is consuming the latent energy, and the steam is condensing to a liquid (condensate); the condensate is drained away by gravity, but the non-condensable gases and air remain.

The non-condensable gases form a stagnant film on the walls of the heat transfer surface, which creates a resistance. Heat energy transmitting through the heat transfer surface has to pass by conduction through these films of resistance. A film of air or non-condensable gases that is only one thousandth of an inch thick has the resistance of a three-inch wall of iron.

The latent heat energy of steam must pass from the steam heat transfer area to the area where the process material is being heated. To do so, it must pass through several obstacles:

- A stagnant film of air/steam on the steam side
- Condensate film
- Buildup of rust or corrosion material
- Heat transfer metal wall
- Product side – burned product or scale
- Stagnant film of material on the process side of the wall

AIR REDUCES THE TEMPERATURE OF STEAM

Dalton's law of partial pressures states that in a mixture of gases or vapors, the total pressure of the mixture is made up of the partial pressures exerted by each gas or vapor. The partial pressure exerted by each is the fraction of the total pressure equal to the fraction of the total volume of each.

The pressure reading is in absolute units. For example, the total pressure of a mixture of 25 percent air and non-condensable gases and 75 percent steam is 114.7 psia (337.87°F).

The partial pressure of steam is 114.7×0.75 or 86.02 psia (317°F). The partial pressure of the air is 114.7×0.25 or 28.56 psia. The temperature of saturated steam at 114.7 psia is 317°F vs. 337.87°F for a steam line or steam component filled with a mixture consisting of 25 percent air and noncondensable gases and 75 percent steam.

There are other steam system issues with the concentration of air and non-condensable gases. The buildup or volume of air and non-condensable gases in the heat transfer area is not constant. The thickness of a stagnant film of air can vary due to velocities, baffles, flow direction, metal finish, and other heat transfer internal designs. This factor can also lead to problems with uneven heating of products.

Plants increase steam pressures to overcome the issues with air and non-condensable gases. In turn, the higher cost of producing higher steam pressures increases the plant's energy cost.

ELIMINATING THE NON-CONDENSABLE GASES OR AIR FROM THE SYSTEM

Devices or methods to vent the non-condensable gas or air

There are several methods to vent air from the system or heat transfer unit.

Manual valve

Negative:

- Requires an employee to operate the device

Positives:

- Plant employee can ensure that all air has been vented from the system
- Plant employee can also drain condensate from the system during startup
- Typically used on steam and pressurized condensate lines

Automatic valve

Negatives:

- Requires an automatic valve with electric or compressed air connections
- More complex
- No method of ensuring all the air has been removed.

Positive:

- Plant employee does not have to be at the location of each valve

Air venting device

Temperature is a key factor that differentiates an air/steam mixture from 100% steam.

Therefore, an automatic air vent, which relies on a thermostatic device for operation, is often used.

The air-venting device typically includes a thermostatic balance pressure bellows unit with a very low sub-cool. The device is able to sense air or non-condensable gases due to the resulting temperature suppression.

The air-venting device is used on the heat transfer units that have shutdowns and startups during the operational week.

Negative:

- Reliability can be an issue if the proper air-venting device is not purchased

Positives:

- No plant personnel have to be at the location during startup
- Greatly improves the operation of the heat transfer system

Steam trap

Steam traps are never considered to be primary air venting mechanisms due to the methods incorporated into their design to accomplish this task. Therefore, steam traps are always considered secondary air vent mechanisms. There are two methods to vent air in any steam trap: a leak path and a thermostatic mechanism.

Create a leak path

The steam trap design has a leak path incorporated into the operational design. The steam trap leak path is very small to ensure no significant steam loss occurs during operation. Due to the small leak path, the steam trap is not able to provide sufficient air venting capabilities.

Thermostatic mechanism

The other method is to use a thermostatic element inside of the steam trap that can offer a high capacity of venting air at startup due to the orifice size. In process applications, the preferred

steam trap is a float and thermostatic steam trap, which incorporates a thermostatic air venting mechanism. Plants often employ one or more of the above items to remove the air from the steam system during startup or operation.

b. Discuss the function of the following components of a typical HVAC system:

- **Blower**
- **Fan**
- **Damper**
- **Chiller**
- **Filter**
- **Heat exchanger**
- **Scrubber**
- **Hood**
- **Pressure sensor**
- **Differential pressure indicator**
- **Compressor**
- **Condenser**
- **Thermal expansion valve**

Blower and Fans

The following is taken from GlobalSpec, “HVAC Fans and Blowers Information.”

HVAC fans and blowers are used to move air through heating, ventilating, and air conditioning systems. They are an integral part of the air handling systems that bring or draw fresh air into buildings. HVAC fans and blowers can be mounted to an exterior wall or above the ceiling, or used as part of a ducted system. The fan spins or the blower turns by means of an electric motor, thus creating unidirectional air flow. Often, the air is pre-heated or cooled. Types of HVAC fans and blowers include vents or ventilation fans, plenum fans, duct fans, duct blowers, roof fans, exhaust fans, inline fans, tube axial fans, vane axial fans, and centrifugal blowers.

HVAC fans and blowers differ in terms of performance and drive options. Parameters include air flow rate, static pressure, and media temperature. Air flow rate is the rate at which air moves within or between HVAC zones. Static pressure is the pressure at which an equal amount of air is supplied to and exhausted from a space. Media temperature is expressed as a range. The diameter of the fan or the diameter or maximum dimension of the blower outlet is also an important specification to consider when selecting HVAC fans and blowers. There are two drive options: direct drive and belt drive.

There are two styles and three classes for HVAC fans and blowers. The two styles are forced draft and induced draft. Forced draft refers to the movement of air under pressure. Forced draft fans and blowers are so named because they force air to move. Induced draft refers to the movement of air by means of an induced partial vacuum. Induced draft fans and blowers draw air. The Air Movement and Control Association (AMCA) class for HVAC fans and blowers describes the device’s compliance with requirements from AMCA.

Design configuration is an important parameter to consider when specifying HVAC fans and blowers. There are three main choices: axial, bi-lobal or tri-lobal, and centrifugal. Axial fans include propeller vans, vane axial fans, and tube axial fans. With these designs, the fan blade circulates parallel to the air flow. Bi-lobal and tri-lobal fans consist of multiple co-rotating, serpentine shafts that mesh to move air and gases in a controlled manner. The shafts mesh so tightly that backflow is prevented. Typically, bi-lobal fans and tri-lobal are used to recirculate

gases in process equipment when environmental consistency is required. Centrifugal fans include products with many different blade configurations. HVAC fans and blowers that use other designs are also available.

Damper

The following is taken from eHow, “How Does a HVAC Damper Work?”

A damper is an adjustable plate for controlling the draft in an HVAC system. Dampers open and close based on the portion of the HVAC system in use, and they control air flow and venting of the system. Depending on how elaborate the HVAC system is, there can be multiple zone dampers, each individually linked to a zone-specific thermostat, which in turn connects back to the master thermostat so that the temperature in each zone can be managed separately.

DAMPER MECHANISM

The damper mechanism is almost always made of lightweight metal that is impervious to heat and cold. In most modern HVAC systems, the damper mechanism is automatic, operated by a small motor, and its movements directed by a thermostatic controller.

ROOM DAMPERS

At the end of each branch of HVAC piping is a terminus vented grate. These grates typically have a lever control that can be moved up and down or left to right to open, close or redirect air flow coming through the louvers. This is a comfort control feature in rooms to prevent, for example, the cool air of an air conditioner blowing directly on someone as they lie in bed. They also serve as a system-wide air flow management control, directing cool or warm air into parts of the home most requiring it and skipping those rooms or areas that do not. An example of this would be western facing rooms, which are heavily covered in windows coping with afternoon sun, as opposed to the eastern side of a home shaded by overhead trees. Irrespective of where in the house the thermostat is placed, the room damper system can aid in efficient energy management in both heating and cooling modes.

Chiller

The following is taken from eHow, “What are HVAC Chillers?”

HVAC chillers are industrial- and commercial-grade refrigerating systems used in cooling applications. The system includes a compressor, evaporator, condenser, reservoir, thermal expansion valve (TXV), and stabilization assembly. HVAC chillers use water, oils, and other liquid compounds as refrigerants.

COOLING CYCLE

When the refrigerant is compressed, it creates a superheated, high-pressure gas. The condenser, using cool air or water, condenses the compressed gas and turns it into a warm liquid. The warm liquid is turned over to the TXV which releases the refrigerant into the evaporator and converts the warm liquid into cool and dry gas. To stabilize the cooling output, a hot-gas bypass may be used to warm up the evaporator. While this reduces the cooling efficiency, it also stabilizes the temperature of the chilled water. From the reservoir, the water is pumped to the compressor, going back to the chilling cycle.

CONDENSER COOLING METHODS

HVAC chillers vary in quality and cost depending on their cooling method and process pump specifications. There are generally two types of condenser cooling methods: air- or water-cooled, as well as variations of the two. Air-cooled condensing methods use a fan to force the cool air over the condenser coils. Water-cooled condensing methods, on the other hand, fill the condenser coils with circulating water. Another common type of condenser cooling method is the remote air or slit cooled condenser chiller system. This type positions the condenser remotely, typically in outdoor settings, by locating the main part of the chiller in the area of application.

Filter

The following is taken from U.S. Environmental Protection Agency, (EPA), “Indoor Air Quality in Large Buildings,” appendix B, “HVAC Systems and Indoor Air Quality.”

Filters are primarily used to remove particles from the air. The filter type and design determine a filter’s efficiency at removing particles of a given size and the amount of energy needed to pull or push air through the filter. Filters are rated by different standards and test methods such as dust spot and arrestance, which measure different aspects of performance.

Heat Exchanger

The following is taken from Wikipedia, “Heat Exchanger.”

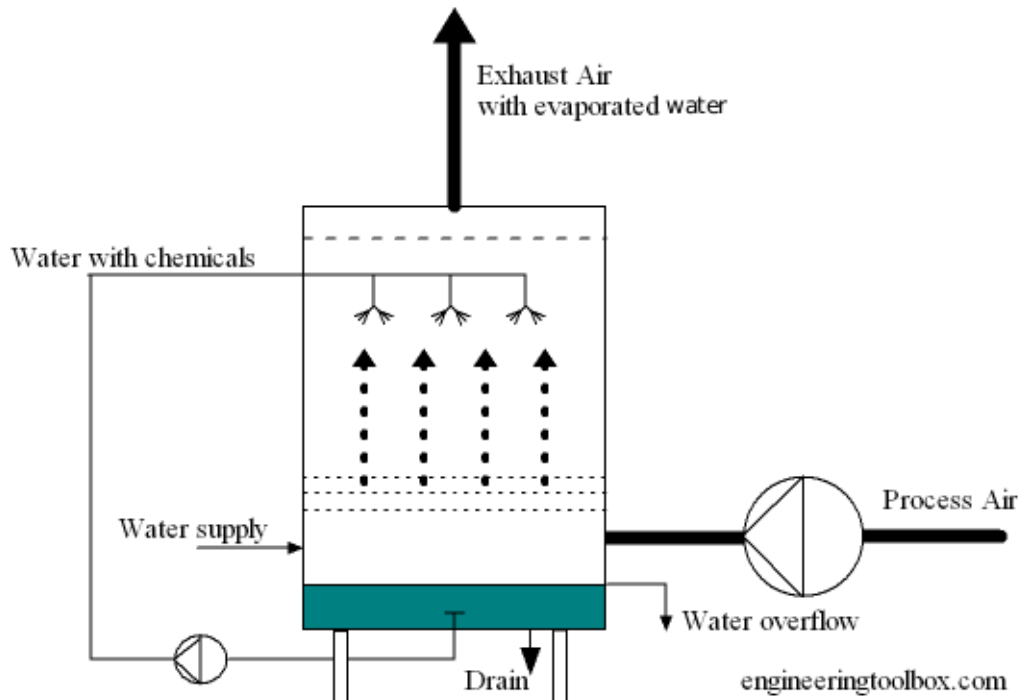
A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall, so that they never mix, or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

Scrubber

The following is taken from The Engineering ToolBox, “Scrubber Basics.”

Air scrubbers are commonly used in process-air applications to eliminate potentially harmful dust and pollutants. A liquid, in general water combined with active chemicals adapted to the process, is sprayed into the air flow. Aerosol and gaseous pollutants in the air stream are removed either by absorption or chemical reactions with the water solution.

A schematic drawing of a typical spray nozzle scrubber configuration is shown in figure 33.



Source: Engineering ToolBox, Scrubber Basics

Figure 33. A typical spray nozzle scrubber configuration

Water with chemicals is sprayed with high pressure through nozzles into the air flow. Some of the water evaporates, especially if the process-air is hot, and disappears with the exhaust. Water droplets are separated from the exhaust and re-circulated back to the water reservoir. Evaporated water is replaced by fresh water and chemicals. Dust and pollution products from the process are removed periodically through the drain.

The basic scrubber configurations include the following:

- Orifice scrubbers—air or gas velocity is increased through an orifice - increased turbulence atomizes the water droplets.
- Venturi scrubbers —air or gas velocity is increased through a venturi shape - increased turbulence atomizes the water droplets.
- Fiber-bed scrubbers—air passes through wet-laden fiber mats where mists are collected. These are not suitable if solid particles are present in the air since the fiber mats may plug.
- Mechanical scrubbers—a mechanical driven rotor produces fine water droplets in the air
- Impingement-plate scrubber—vertical scrubber with horizontal plates, air flows from bottom to top, water flows from top to bottom.
- Spray nozzle scrubbers—water is sprayed with high pressure through nozzles to produce droplets in the air.

Hood

According to Laboratory Network.com, typical fume hoods circulate air through their sashes at 100 ft/min. The energy to filter, move, cool or heat, and, in some cases, scrub (clean) this air is one of the largest loads in most lab facilities. In the conventional fume hood design, air is sucked in through the sash and vented out the top.

Pressure Sensor

The following is taken from Wikipedia, “Pressure Sensor.”

A pressure sensor measures pressure, typically of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area. A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed. For the purposes of this article, such a signal is electrical.

Pressure sensors are used for control and monitoring in thousands of everyday applications. Pressure sensors can also be used to indirectly measure other variables such as fluid/gas flow, speed, water level, and altitude. Pressure sensors can be called a variety of names, including pressure transducers, pressure transmitters, pressure senders, pressure indicators, piezometers, and manometers, among others.

Pressure sensors can vary drastically in technology, design, performance, application suitability, and cost. A conservative estimate would be that there may be over 50 technologies and at least 300 companies making pressure sensors worldwide.

There is also a category of pressure sensors that are designed to measure in a dynamic mode for capturing very high speed changes in pressure. Example applications for this type of sensor would be in the measuring of combustion pressure in an engine cylinder or in a gas turbine. These sensors are commonly manufactured out of piezoelectric materials such as quartz.

Differential Pressure Indicator

The following is taken from Purolator, “Indicators.”

Differential pressure devices sense the differential pressure directly across the filter element. At a preset limit, the indicator will actuate, signaling the need to change the filter element. This permits maximum use of the element, requiring element changing only when the full dirt holding capacity is reached, rather than changing elements on a periodic time basis, which may result in premature disposal of still useful elements. Differential pressure devices actually reduce plant operating costs by signaling the need for element replacement only when the elements have removed their designed dirt holding capacity.

Compressor

The following is taken from Air Conditioning Filter, “HVAC Compressor.”

The compressor is the central functioning unit of any cooling system and the same is true of the HVAC compressor. In general, a compressor is a mechanism that, as its name suggests, compresses gas by diminishing its volume. This is the primary basis of any HVAC system.

Condenser

The following is taken from Wikipedia, “Condenser.”

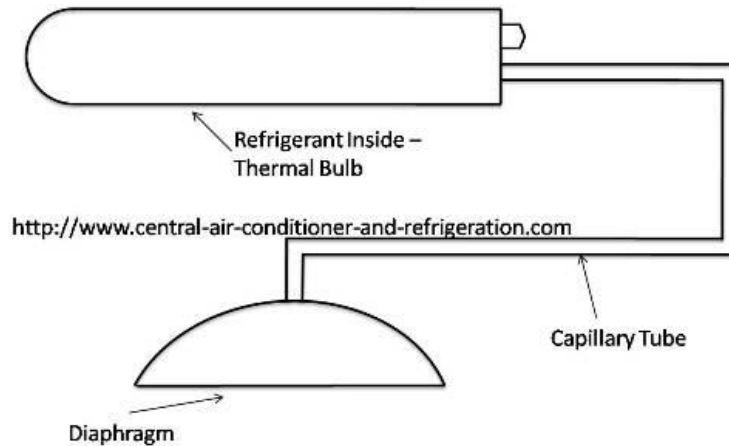
In systems involving heat transfer, a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant. Condensers are typically heat exchangers which have various designs and come in many sizes ranging from rather small (hand-held) to very large industrial-scale units used in plant processes. For example, a refrigerator uses a condenser to get rid of heat extracted from the interior of the unit to the outside air. Condensers are used in air conditioning, industrial chemical processes such as

distillation, steam power plants, and other heat-exchange systems. Use of cooling water or surrounding air as the coolant is common in many condensers.

Thermal Expansion Valve

The following is taken from Central Air Conditioning and Refrigeration, “Thermostatic Expansion Valve.”

The thermal expansion valve (TXV), as shown in figure 34 is used for refrigerant flow control and operates at varying pressures resulting from varying temperatures. This valve maintains constant superheat in the air conditioner evaporator.



Source: Central Air Conditioning and Refrigeration, Thermostatic Expansion Valve

Figure 34. Thermal expansion valve

The thermostatic expansion valve needs a capillary tube and thermal element (bulb) to work. The capillary tube connects the element to the top of TXV diaphragm.

The element is partly filled with a liquid refrigerant and maintains some liquid under all conditions of temperature and load.

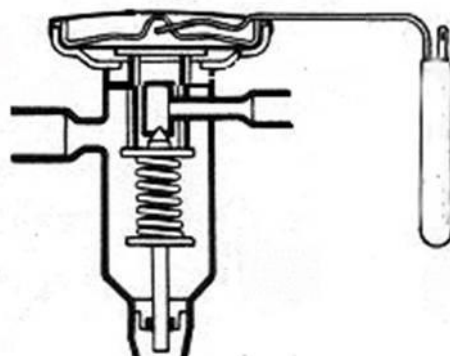
A cross section of thermostatic expansion valve components and the operation principles are shown in figure 35.

The three forces that control the operation of the TXV are:

P1—The vapor pressure of the thermostatic element (a reaction to the bulb temperature) which acts to open the valve.

P2—The evaporator pressure which acts in a closing direction below the diaphragm.

P3—The pressure equivalent of the superheat spring force which is also applied underneath the diaphragm in a closing force.



Source: Central Air Conditioning and Refrigeration, Thermal Expansion Valve

Figure 35. TXV components

When a change in temperature in the suction line occurs, the pressure in the thermal bulb also changes similarly. With an increased heat load, the refrigerant in the evaporator coil boils quickly.

This results in a rise in temperature at the thermal bulb because of superheating. The higher temperature produces an increase in pressure within the thermal bulb due to superheating.

The higher temperature produces an increase in pressure within the thermal bulb which increases the pressure at P1. The pressure in the evaporator at P2, and the spring pressure in the TXV at P3 remains constant.

Therefore, with the increased pressure at P1, the bellows (diaphragm) expands to force a wider valve opening. As a result, more refrigerant is allowed to enter the evaporator to compensate for the increased heat load.

The increase in flow rate increases to evaporator pressure P2, which establishes a balance control once again. With a decreased load the reverse cycle takes place.

The capacity of a TXV varies due to orifice size, pressure difference between high and low side, and the temperature and condition of the refrigerant in the liquid line.

The amount of liquid that will flash to a vapor will increase with a rise in liquid line temperature. The capacity of most valves, however, maybe determined by the orifice size and needle assembly. The body size remains the same for many capacities.

Thermostatic expansion valves are rated in tons of refrigeration. However, three different tonnage capacities are usually provided for the same orifice. The range of capacity depends on the difference in pressure between the high and the low side of the system.

Using the appropriate capacity valve is very important: If the valve orifice is too small, the evaporator will be starved regardless of the superheat setting. The full capacity of the evaporator will never be obtained. However, if the valve orifice is oversized, too much refrigerant will pass into the evaporator and the suction line will sweat or frost before the thermal element can close the valve.

Evaporator Coils

The following is taken from WiseGeek, “What is an Evaporator Coil?”

An evaporator coil is a vital part of any heating or cooling system. It is usually found in an air conditioner because evaporator coils are good at absorbing heat when air is passed through them. Evaporator coils look like a series of pipes. A furnace, central air conditioner, or other air-modifying device passes the air through the evaporator coil, which absorbs the air’s heat and sends it back into the building as cold air via a series of air ducts. The two main components of an air conditioner are usually the condenser and the evaporator coil.

Central furnace and air conditioning combinations often have their condenser and evaporator coil close together. These units can use the condenser to heat the air or switch over to the evaporator coil to cool the building. Evaporator coils will typically be placed on top of or next to an air-handling unit, rather than inside of it. In North America, there are three common types of evaporator coils:

1. The vertical evaporator coil is best suited to handle an upward or downward air flow. It handles pre-processed air and condenses the heat from this air flow in water form. After the

condensation process, the vertical coil channels the resulting water to a drain, thereby lowering the humidity of the air as it cools it.

2. Cased evaporator coils have a protective outer shell and are one of the most commonly used models. Like vertical coils, they handle an upward or downward air flow, using a coolant to attract hot air and leave only the colder air current. This cold air returns to the building after passing through the air conditioning ducts. The cased evaporator coil's function is almost identical to that of the vertical coil, but the main difference lies in their shape and size. Depending on the type and configuration of the air conditioning device or furnace being used, one model may fit better than the other for installation purposes.
3. The third common type of coil is the uncased evaporator coil, which is a version of the cased evaporator coil minus its protective casing. An uncased evaporator coil is much easier to customize for this reason. It is a good choice for those with a unique furnace or air conditioning unit because technicians can reconfigure the coil shape to fit the device in question.

Receiver

The following is taken from Heat Air Conditioning, "Receiver."

The receiver is a refrigeration accessory that is a storage tank used to accumulate liquid refrigerant from the condenser.

Ideally, the refrigeration system boils off the refrigerant in the evaporator at the same rate it condenses in the condenser resulting in a uniform rate of refrigerant flow throughout the system. In small systems, such as domestic refrigerators and room air conditioners, this can be achieved, and receivers are not needed.

However, in larger systems this is not the case, and receivers are used as temporary storage containers of liquid refrigerant. Receivers are also useful as storage tanks for the refrigerant during shut-down.

c. Discuss refrigerant leak detection.

The following is taken from Contracting Business Magazine, "Refrigerant Leak Detection."

All pressurized HVAC systems can eventually leak refrigerant. Therefore, it is the responsibility of the HVAC technician to monitor systems regularly and inspect for leaks.

Although a tight system with minimal leakage that does not affect system performance may not pose a problem, a more serious leak will do so, and could occur at any time.

Some leaks are plainly visible to the eye. These include a visible line break, the presence of oil, and quite possibly a refrigerant vapor cloud of escaping gas.

An audible leak might also be detected if a system is pressurized and large leaks are present.

Leak detection has become greatly enhanced through the use of modern instruments designed to detect very small amounts of refrigerant and leakage.

When a technician has difficulty determining the source of a reduced refrigerant charge, additional detection methods are needed. There are various methods of leak detection, and more than one method may be necessary to conduct a thorough system diagnosis.

When verifying a refrigerant charge, any system appearing low should be suspected of leakage. Topping off the charge is generally acceptable when single compound refrigerant systems are serviced. However, it is not acceptable for zeotropic refrigerant blends (blends of two or more components whose equilibrium vapor-phase and liquid-phase compositions are different at given pressures). When vapor leakage occurs, a variation or percentage of the refrigerants in the blended compound is compromised. Recovery of the charge, repair of the system, and re-charging with renewed or virgin refrigerant is needed.

The standing hold method is often performed on new systems after assembly, but before the final full charging with refrigerant. The EPA allows for a trace amount of R-22 (to about 10 psig) to be added as a detectable gas.

Pressure is increased in the system with dry nitrogen to the low side working maximum pressure (typically 100-150 psig). Pressure is then monitored using a pressure gauge for several hours or longer as needed. If the system being tested has already been charged, then recovery and evacuation of the refrigerant is done before this test.

Minor changes in temperature generally do not affect the pressure indication of nitrogen, as the same temperature variation would affect a refrigerant pressure-to-temperature relationship. This is a reliable but time consuming method of leak detection. On existing systems, the refrigerant operation must also be shut down during the test. If a leak is detected, it must be found, and often additional methods and tools are needed.

Remember that the service ports can be a leak site. These should be checked after attaching the gauge hoses. Also, remember to check the manifold gauge set for leakage.

The isolation method is used in addition to the standing hold test when areas of the system or tubing cannot be accessed. This method requires breaking open the refrigerant piping system (after the charge has first been removed), then re-sealing it and pressure-testing it for leakage.

Bubbling liquid solutions are liquid solutions that bubble up when placed on a leak site. The solution can be applied by spray, dabber, brush, or immersion. A technician can use this method to verify specific leakage points when other methods indicate a general area. The solution can be a messy procedure, and requires time-consuming clean up to remove residue unless the product manufacturer indicates the solution is not damaging or corrosive.

The halide torch method is used for detecting chlorinated refrigerant leaks of one ounce per year or less. Air is drawn over a copper element heated by a hydrocarbon fuel. If halogenated refrigerant vapors are present, the flame changes from a blue color to a bluish green color.

Safety Precaution: With an open flame, additional safety must be considered to prevent property damage, burns, fire, and inhalation hazards. Make sure the area is also absent of combustible mixtures and other flammables.

With the dye injection method, a dye is injected into the refrigerant-charged system. It will seep out of system cracks, and is then usually detectable. A fluorescent type dye, if used, is detectable under ultra-violet light. This also requires access to all areas of the system, as they need to be inspected for dye leakage indicators. The system may also have to operate for several hours before the leak is detected. Determine first if the compressor manufacturer allows dyes to be used on the system during the warranty period, because moisture contamination is possible. This method requires some time consuming clean up.

Ultra-sonic devices are used to listen for leaks. These will amplify noises caused by leaks. Since many ambient noises may be present, there are limitations to using this detector. It is most effective when the surrounding area is very quiet.

d. Discuss the general hazards involved in handling refrigerants.

The following is taken from Refrigerants, “Material Safety Data Sheets.”

Refrigerant safety is straightforward: If the refrigerant stays contained in the cylinder or in the system then it presents little danger to people. The hazard occurs when the refrigerant comes out of the container or system, often quickly and unexpectedly. Injuries can be avoided if regular safety checks are performed.

Regular checks on containers and systems for holding pressure, and preparing safety equipment and procedures to minimize personal exposure after unexpected releases should help avoid any injuries when handling refrigerants.

Specific hazards from refrigerants fall into three categories:

1. Toxicity
2. Combustion/flammability/decomposition
3. Elevated Pressure

Toxicity and Personal Exposure

Most refrigerants have undergone extensive toxicity testing before being released for general refrigeration or air conditioning use. Testing generally involves a range of exposure levels and times to determine any possible effects on test animals.

- Short term exposures at high concentrations indicate any acute hazards such as irritation, sensitization of the heart or adrenals, and lethal concentration levels.
- Tests that expose animals for longer periods of time, such as 90 days to two years, are designed to indicate chronic problems. These can include mutagenicity, reproductive problems, effects on organs, or carcinogenicity.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 34, *Designation and Safety Classification of Refrigerants* provides a safety classification for refrigerants based on information related to personal exposure. ASHRAE Standard 15, *Safety Standards for Refrigeration Systems* uses this safety rating and additional toxicity information to set requirements for machinery rooms and sets limits on the amount of refrigerant allowed in systems outside machinery rooms. Many blends containing these individual components are also classified.

Refrigerants not classified in ASHRAE Standard 34 should be reviewed with suppliers to make sure enough is known about their toxicity properties. Some blends may not be classified, but contain classified components.

Exposure levels are values given to refrigerants to indicate how much of the chemical a person can regularly be exposed to without adverse effects. All toxicity test results are considered when setting this level. The American Conference of Government and Industrial Hygienists (ACGIH) sets the threshold limit value-time weighted average (TLV-TWA) values for chemicals. TLV-TWA is the amount of chemical a person can be exposed to for 8 hours a day, 40 hours a week, without adverse effects.

The maximum value for any chemical is 1,000 ppm, though many refrigerants have shown no effects in toxicity testing at values much higher than that. Other organizations and chemical producers have similar exposure level indexes based on the same criteria. These are the Workplace Environmental Exposure Limit set by the American Industrial Hygiene Association; permissible exposure limit set by OSHA; and acceptable exposure limit used by DuPont.

There are also the short term exposure limits, which are based on a 15-minute exposure time in any given day as well as the value immediately dangerous to life or health. These are used to give guidance for machinery room requirements, ventilation and alarms in emergency or escape situations, or in circumstances where short releases of refrigerant are expected, which could include refrigerant transfers or servicing large equipment.

Toxicity data is usually summarized in great detail on material safety data sheets (MSDS). What all of this data means to the technician, however, is that commercial refrigerants are safe enough to use provided that inhalation is minimal. Industry practices for handling refrigerants are intended to minimize personal exposure as well as reduce releases into the atmosphere.

General rules to observe include the following.

- Minimize the amount of refrigerant released. Proper recovery procedures, including clearing hoses, will keep the refrigerant in the containers instead of potentially exposing it to people.
- Never intentionally release refrigerant in a confined space. Even the safest refrigerant can still displace enough oxygen to cause suffocation.
- Set up ventilation equipment, like a portable fan, in areas where possible release would mean high concentrations.
- Refer to ASHRAE Standard 15 and local building codes for additional guidance.

If someone is exposed to refrigerant get them to fresh air, give oxygen if needed, and get them checked by a doctor.

Flammability/Combustion/Decomposition

Flammable refrigerants present an immediate danger when released into the air. The refrigerant can combine with air at atmospheric pressure and ignite, causing a flame and possibly an explosion to occur. Because of the obvious hazards, the use of flammable refrigerants is restricted to controlled environments that have monitors, proper ventilation, explosion-proof equipment and generally few people near the equipment.

Some refrigerants can burn with oxygen, but only at higher pressures or temperatures and never in air at atmospheric conditions. These are called combustible refrigerants. Underwriters Laboratories lists these refrigerants as practically nonflammable.

R-22 and R-134a fall into this category. R-22 was found to cause a combustion hazard during a pressurized leak test with air. For this reason, most refrigerants should be used only with pressurized nitrogen for leak testing. As long as refrigerant is not mixed with large amounts of air, there should be little hazard from these refrigerants during normal handling and use.

Decomposition can occur with any refrigerant when it gets hot enough. Refrigerant can decompose in systems or containers exposed to fire or other extreme heat, electrical shorts, or in refrigerant lines being soldered or brazed without being cleared first. Obviously, refrigerant containers or charged systems should never intentionally be exposed to a flame or torch.

When a refrigerant is decomposed or burned, the primary products formed are acids: Hydrochloric acid, if the refrigerant contains chlorine, and hydrofluoric acid, if it contains fluorine. These products are certainly formed when hydrogen is present, such as from the breakdown of oil or water, or if the refrigerant has hydrogen attached. If oxygen also is present, then it is possible to form carbon monoxide, carbon dioxide, and various unsaturated carbonyl compounds, the most notorious of which is phosgene.

Being extremely toxic in small amounts, phosgene formation was a real concern when traditional refrigerants decomposed. Phosgene contains two chlorine atoms and an oxygen atom. It will only form when oxygen is present and only the refrigerants with chlorine attached will produce phosgene. R22 has only one chlorine atom per molecule, so it is extremely difficult, chemically speaking, to get another one attached to form phosgene. Decomposition of R-22 may form other carbonyl fluorides, however they are not as toxic as phosgene.

The standard practice for handling decomposed refrigerant is to collect the gas, treat the refrigerant and/or the system for acid contamination, and appropriately dispose of the burnt gas. Please note that any cylinder or system component exposed to high heat or fire should be retested or discarded. Cylinders used to recover burnt gas should be checked and cleaned before being put back into service, especially the valve and/or pressure relief device.

Physical Hazards

The fact that it is a liquefied gas under pressure is one of the more obvious hazards of refrigerant. Sudden, unexpected release of pressurized refrigerant can result in personal injury.

Frostbite: liquid refrigerant suddenly released from high pressure to atmospheric pressure will flash and boil to vapor. Naturally, the temperature of the refrigerant will drop quickly to the boiling point and the refrigerant will quickly absorb heat from whatever it is touching. If the refrigerant is touching skin it can cause frostbite.

Frostbite damages skin by freezing water inside the skin cells, which can expand and burst the cell walls. To treat frostbite, cover the exposed area with warm (not hot) water or a wet compress. The skin must recover slowly or more damage can occur. Do not rub the affected area to try to warm it as it may inflict more damage. Protective clothing, gloves and eye protection are effective at preventing frostbite by keeping liquid refrigerant away from the skin.

Rupture of tank or system: cylinders or systems without pressure relief devices could break if the refrigerant pressure inside were to exceed the strength of the cylinder or system component. This type of failure can be quite hazardous if the refrigerant is at a high pressure or solid material is blown loose. Containment failures are caused by one of two things: The refrigerant pressure has increased above the pressure rating of the cylinder or system, or something has happened to the cylinder or system so that it will no longer hold normal refrigerant pressure.

Elevated refrigerant pressure can be caused by exposure to heat. Refrigerants with pressures similar to R-12 will develop more than 500 psia at temperatures above 200°F. Refrigerants with pressures similar to R-502 will achieve the same pressures at about 150°F. Hydrostatic pressure also can develop quickly in a confined volume that has been completely filled with liquid refrigerant, for example liquid-full hoses between shut valves or an overfilled recovery cylinder.

Refrigerant tubing, hoses, system components, and some refrigerant cylinders surely would fail at some elevated pressure without certain safety provisions. Various pressure relief devices are used to lower the pressure back to safe limits by releasing some or all of the refrigerant.

Valves on many refrigerant cylinders are fitted with spring-loaded pressure relief valves. These are typically set to release pressure somewhere above typical refrigerant pressures at normal use or transportation temperatures, but below the maximum service pressure of the cylinder. When the pressure is reduced to a safe level the valve should close itself.

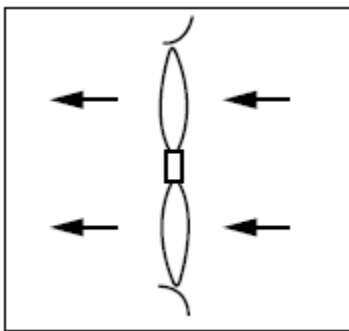
Other cylinders or storage vessels are fitted with burst discs as the pressure relief device. These are pieces of metal designed to break at some preset pressure, again lower than the maximum service pressure of the container. In the case of a burst disc, the entire contents of the container will be released. This is also the case with a fusible plug, which is designed to melt at a certain temperature. It's used to relieve the pressure in a tank or system in a fire situation before the pressure gets high enough to burst the tank, tubing, or system component.

Damaged or weakened refrigerant cylinders or system components may fail at pressures lower than originally specified. Physical abuse such as dents, scratches, rust, bulges, or exposure to excessive heat can reduce the strength of joints or the metal itself. Materials originally designed to hold hundreds or thousands of psi pressure might now fail at typical refrigerant pressures. In the case of damaged cylinders, the pressure relief device shouldn't be relied upon for protection; the cylinder should be repaired and retested or discarded.

The best way to avoid pressure-related hazards is to always use cylinders and system components that have the correct pressure rating for the refrigerant being used. Table 1 lists the typical cylinder service pressures that manufacturers and distributors use for various refrigerants. Pressure ratings for system components must be chosen based on the application and expected service pressures for the intended application. Pressure ratings are also based on the refrigerant chosen. Always check for signs of damage or excessive wear before filling recovery cylinders, picking up new refrigerant cylinders or attaching new parts to a system.

e. Compare and contrast the design, operation, and application of axial-flow and radial-flow fans.

The following is taken from Clarage Engineering Data, "Fan Performance Characteristics of Centrifugal Fans."



Source: Clarage Engineering Data, Fan Performance Characteristics of Centrifugal Fans

Figure 36 . Axial-flow

There are two general classifications of fans: the propeller or axial flow fan and the centrifugal or radial flow fan. In the broadest sense, what sets them apart is how the air passes through the impeller. The propeller or axial flow fan propels the air in an axial direction (figure 36) with a swirling tangential motion created by the rotating impeller blades.

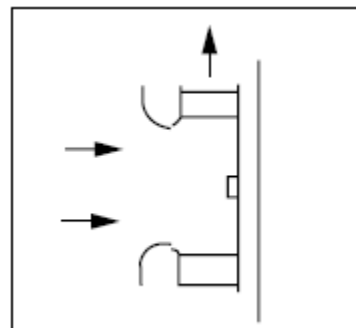
In a centrifugal fan, the air enters the impeller axially and is accelerated by the blades and discharged radially (figure 37). The one exception to this is the tangential transverse fan where the air enters and discharges radially through the impeller.

The axial flow fan increases the air velocity through rotational or tangential force which produces velocity pressure (VP), kinetic energy, with a very small increase in static pressure (SP), potential energy.

The centrifugal fan induces airflow by the centrifugal force generated in a rotating column of air producing potential energy and also by the rotational (tangential) velocity imparted to the air as it leaves the tip of the blades producing kinetic energy.

f. Discuss the relationships among the following in ventilation systems:

- **Supply ventilation**
- **Flow**
- **Exhaust ventilation**



Source: Clarage Engineering Data, Fan Performance Characteristics of Centrifugal Fans

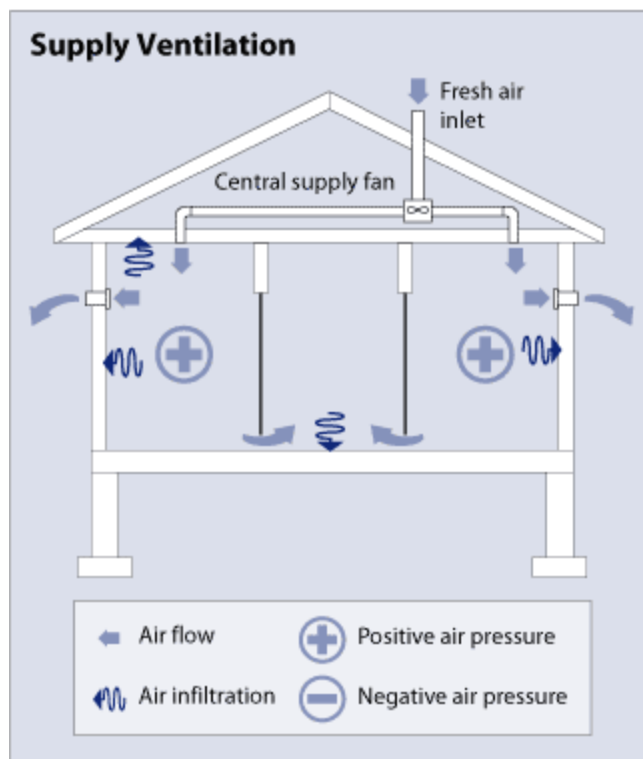
Figure 37. Radial-flow

Supply Ventilation

The following is taken from DOE Energy Efficiency & Renewable Energy, “Whole House Supply Ventilation Systems.”

Supply ventilation systems work by pressurizing the building. They use a fan to force outside air into the building while air leaks out of the building through holes in the shell, bath and range fan ducts, and intentional vents (if any exist).

As with exhaust ventilation systems, supply ventilation systems are relatively simple and inexpensive to install. A typical supply ventilation system has a fan and duct system that introduces fresh air into usually one—but preferably several—rooms of the building that are occupied most often. This system may include an adjustable window or wall vents in other rooms.



Source: DOE Energy Efficiency & Renewable Energy, Whole House Supply Ventilation Systems

Figure 38. Supply ventilation

Supply ventilation systems allow better control of the air that enters the house than do exhaust ventilation systems. By pressurizing the house, supply ventilation systems discourage the entry of pollutants from outside the living space and prevent back drafting of combustion gases from fireplaces and appliances. Supply ventilation also allows outdoor air introduced into the house to be filtered to remove pollen and dust or dehumidified to provide humidity control.

Supply ventilation systems work best in hot or mixed climates. Because they pressurize the house, supply ventilation systems have the potential to cause moisture problems in cold climates. In winter, the supply ventilation system causes warm interior air to leak through random openings in the exterior wall and ceiling. If the interior air is humid enough, some moisture may

condense in the attic or cold outer parts of the exterior walls where it can promote mold, mildew, and decay.

Like exhaust ventilation systems, supply ventilation systems do not temper or remove moisture from the make-up air before it enters the house. Thus, they may contribute to higher heating and cooling costs compared with energy recovery ventilation systems. Because air is introduced in the house at discrete locations, outdoor air may need to be mixed with indoor air before delivery to avoid cold air drafts in the winter. An in-line duct heater is another option, but it will increase operating costs.

Flow

The following is taken from Northern Arizona University, “Ventilation and Air Flow.”

Ventilation air, as defined in Standard 62.1-2010, *Ventilation for Acceptable Indoor Air Quality*, is that air used for providing acceptable indoor air quality. When people or animals are present in buildings, ventilation air is necessary to dilute odors and limit the concentration of carbon dioxide and airborne pollutants such as dust, smoke, and volatile organic compounds.

Ventilation air is often delivered to spaces by mechanical systems which may also heat, cool, humidify, and dehumidify the space. Air movement into buildings can occur due to uncontrolled infiltration of outside air through the building fabric or the use of deliberate natural ventilation strategies. Advanced air filtration and treatment processes such as scrubbing, can provide ventilation air by cleaning and/or recirculating a proportion of the air inside a building.

Ventilation is one of the most important engineering controls available to the building manager for improving or maintaining the quality of the air in the occupational work environment. Broadly defined, ventilation is a method of controlling the environment with air flow.

The sense of thermal comfort (or discomfort) results from an interaction between air temperature, relative humidity, and air movement.

Air flow is also important for ensuring that air moves from clean to dirty and out. In general, the air flow patterns should move from ‘clean’ spaces into ‘more dirty’ areas. A good rule of thumb is to keep air flowing from clean to dirty, so that children are not breathing polluted air. This is particularly important for places such as janitorial closets where cleaning supplies are often stored, unused locker rooms with dry traps and leaking sewer gases, and boiler rooms with back drafting heating appliances.

Exhaust Ventilation

The following is taken from North Carolina State University, “Exhaust Ventilation for Hazardous Materials.”

The primary purpose of local exhaust ventilation is to protect the employee from hazardous airborne exposures. Local exhaust ventilation systems include exhaust fans, their associated ductwork, and typically a work enclosure or material enclosure. Exhausted work stations include, but are not limited to, fume hoods, laminar flow chemical hoods, and exhausted biological safety cabinets. Gas cylinder cabinets and exhausted equipment enclosures are examples of material enclosures.

In order for exhaust systems to function effectively they must be designed, installed, maintained, and used according to recognized standards and good work practices.

g. Describe the purpose of the ventilation system in the following applications:

- **Hoods**
- **Gloveboxes**
- **Hot cells**
- **Confinement systems**

Hoods

The following is taken from Washington State Department of Labor & Industries, “Industrial Ventilation Guidelines.”

A hood is designed to confine or capture the contaminant at its source. The air velocity at the hood opening and inside the hood must be sufficient to capture and carry the air contaminants. The hood should enclose the source of contaminant as much as possible or be placed as close to the source as possible.

Air velocity in local exhaust systems is measured in feet per minute (FPM). Volume of air through a local exhaust system is measured in cubic FPM, which is simply the air velocity times the area of the hood opening. Sometimes air velocity is measured indirectly by measuring air pressure in the ductwork of the system. The pressure inside a local exhaust system is slightly negative compared to the pressure outside the system and is measured in units called inches of water. This negative pressure varies through the system and is usually measured to determine how well the system is functioning.

Although enclosing hoods provide the best control, they are often not feasible because they would interfere with the work being done by the employee. In those cases, a capture exhaust hood can only be located near the source of the contaminant. These type of hoods reach out to capture the contaminant much like a vacuum cleaner sucking dirt off a floor. However, the distance between the face of the hood and source must be short to effectively capture the contaminant. A hood moved from two inches away from a source to four inches away from a source will require four times the amount of air volume through the system to provide the same degree of capture. Adding a flange to the edges of the capturing hood provides more efficient capture of contaminants. Wide and flat hoods or hoods with slots do not have a greater reach, rather they just spread out the airflow over a wide distance. Their most common use is along the edge of tanks containing volatile chemicals.

Canopy hoods are not recommended for use in local exhaust ventilation because even slight cross-drafts can push contaminants out into the work area and because they often draw air through the breathing zone of an employee working at them.

Gloveboxes

The following is taken from Wikipedia, “Glovebox.”

A glovebox (or glove box) is a sealed container that is designed to allow one to manipulate objects where a separate atmosphere is desired. Built into the sides of the glovebox are gloves arranged in such a way that the user can place their hands into the gloves and perform tasks inside the box without breaking containment. Part or all of the box is usually transparent to allow the user to see what is being manipulated. Two types of gloveboxes exist: one allows a person to work with hazardous substances, such as radioactive materials or infectious disease agents; the other allows manipulation of substances that must be contained within a very high

purity inert atmosphere, such as argon or nitrogen. It is also possible to use a glovebox for manipulation of items in a vacuum chamber.

Hot Cells

Video 29. Hot cell

<http://www.bing.com/videos/search?q=Hot+cells&view=detail&mid=9A888CFD0428D3336AAB9A888CFD0428D3336AAB&first=0>

The following is taken from Wikipedia, “Hot Cell.”

Hot cells are used to inspect spent nuclear fuel rods and to work with other items which are high-energy gamma ray emitters. For instance, the processing of medical isotopes, having been irradiated in a nuclear reactor or particle accelerator, would be carried out in a hot cell. Hot cells are of nuclear proliferation concern, as they can be used to carry out the chemical steps used to extract plutonium from reactor fuel. The cutting of the used fuel, the dissolving of the fuel, and the first extraction cycle of a nuclear reprocessing PUREX process (highly active cycle) would need to be done in a hot cell. The second cycle of the PUREX process (medium active cycle) could be done in gloveboxes

Confinement Systems

The following is taken from DOE-HDBK-1132-99.

Safety ventilation and off-gas systems are generally designed to operate in conjunction with physical barriers to form a confinement system that limits the release of radioactive or other hazardous material to the environment and prevents or minimizes the spread of contamination within the facility. Confinement systems should be designed to

- prevent (if possible) or minimize the spread of radioactive and other hazardous materials to occupied areas;
- minimize the release of radioactive and other hazardous materials in facility effluents during normal operation and anticipated operational occurrences;
- minimize the spread of radioactive and other hazardous materials within unoccupied process areas; and
- limit the release of radioactive and other hazardous materials resulting from accidents, including those caused by severe natural phenomena and man-made events.

The specifics of confinement system design, as they relate to a particular facility, should be guided by an iterative process between safety analyses and design. Safety analyses define the functional requirements of the design, such as the type and severity of accident conditions that the confinement system must accommodate. The design should also consider sources of functional design requirements including maintenance, operability, and process requirements.

Confinement system features, including confinement barriers and associated ventilation systems, are used to maintain controlled, continuous airflow from the environment into the confinement building, and then from uncontaminated areas of the building to potentially contaminated areas, and then to normally contaminated areas.

For a specific nuclear facility, the number and arrangement of confinement barriers and their design features and characteristics are determined on a case-by-case basis. Typical factors that affect confinement system design are the type, quantity, form, and conditions for dispersing the hazardous material, including the type and severity of potential accidents. In addition,

alternative process and facility design features may reduce potential hazards and the resulting requirements for confinement system design. Engineering evaluations, trade-offs, and experience are used to develop a practical design that achieves confinement system objectives. Because the number and arrangement of confinement systems required for a specific nuclear facility design cannot be predicted, this discussion describes a conservative confinement system design that uses the three principal confinement systems described below. The discussion assumes that three levels of confinement are necessary or justified. Design decisions for a specific facility should address that facility's hazards and other factors.

- Primary confinement is usually provided by piping, tanks, gloveboxes, encapsulating material, and the like, and any off-gas system that controls effluent from within the primary confinement. It confines hazardous material to the vicinity of its processing.
- Secondary confinement is usually provided by walls, floors, roofs, and surrounding the process material or equipment. Except for glovebox operations, the area inside this barrier provides protection for operating personnel.
- Tertiary confinement is provided by the walls, floor, roof, and associated ventilation exhaust system of the facility. Tertiary confinement provides a final barrier against release of hazardous material to the environment.

h. Identify and discuss the circumstances under which maintaining a negative ventilation system pressure is desirable.

The following is taken from DOE-HDBK-1169-2003.

The ducts of engineered safety feature (ESF) air cleaning systems that pass through clean areas should be designed at a higher negative pressure, and the length of any air cleaning unit positive pressure discharge ducts that must pass through a clean space should be kept as short as possible. When an ESF air cleaning system is a habitability system, ducts carrying outside air that are routed through clean space should be designed at a negative pressure. Housings handling recirculated habitability air should be at a positive pressure when located in a contaminated space. Negative pressure ducts located in a contaminated space should be avoided. When this is not possible, all-welded duct construction should be used. The length of positive pressure ducts outside the habitability zone should be kept as short as possible.

Generally, the direction of airflow should be from less contaminated spaces toward areas with a higher level of contamination. All ducts and housings containing a contamination level higher than surrounding areas should be maintained at a negative pressure. Ducts and housings with lower concentration levels than surrounding areas should be at a positive pressure. Allowable leakage depends on the difference between duct/housing concentrations and surrounding area concentrations. For example, a once-through contaminated exhaust filter housing serving a radioactive waste handling area in a nuclear power plant may have the exhaust fan located downstream of the filter housing when the housing is located in a space that is cleaner than the air entering the housing. The benefit of this system configuration is that the air cleaning system is under a negative pressure up to the fan. Therefore, leakage will be into the housing, and the potential impact of contaminated leakage on plant personnel during system operation will be minimized.

Such a system configuration does not mean that leakage can be ignored. Where it is crucial to personnel habitability, acceptable limits should be established and periodically verified by testing and surveillance. Rather, it means the potential for exposure has been reduced to as low

as reasonably achievable (ALARA) levels by system design. When the space in which an air cleaning system housing is located is more contaminated than the air entering the housing, it would be better to locate the fan on the inlet side of the housing to eliminate in-leakage of more contaminated air.

When the housings of habitability systems are located within a protected space, the fan should be located downstream of the filter unit to ensure that only cleaner air can leak into the housing. When the housing of a habitability system is located in an area outside a protected space, the fan should be located upstream of the filter unit to ensure that contaminated air cannot leak in downstream of the filter unit.

Location of fans and housings should be accomplished by assigning a positive designation to the atmosphere in the cleaner area or duct, and a negative designation to the more contaminated area or duct. When the pressure difference within an air cleaning housing or duct is positive (+), the fan should be on the contaminated air-entry side; when the pressure difference is negative (-) the fan should be on the “clean air” exit side.

Mandatory Performance Activities:

- a. Given a diagram of a basic HVAC system, discuss the theory of operation of HVAC systems and identify the system’s components and their functions.**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity.

11. Mechanical systems personnel shall demonstrate working level knowledge of general piping systems.

- a. Define the following terms as they relate to piping systems:**

- **Pipe schedule**
- **Water hammer**
- **Hydrostatic test pressure**
- **Laminar flow**
- **Turbulent flow**

Pipe Schedule

The following is taken from The Engineering ToolBox, “Schedule Terminology.”

For all pipe sizes the outside diameter remains relatively constant. The variations in wall thickness affects only the inside diameter.

A schedule number indicates the approximate value of

$$\text{Sch.} = 1000 \text{ P/S}$$

where

P = service pressure (psi)

S = allowable stress (psi)

The higher the schedule number is, the thicker the pipe is. Since the outside diameter of each pipe size is standardized, a particular nominal pipe size will have different inside pipe diameter depending on the schedule specified.

Video 30. Pipe schedule

<http://www.bing.com/videos/search?q=pipe+schedule&view=detail&mid=AA8F6A3E8996360F645CAA8F6A3E8996360F645C&first=0>

Water Hammer

The following is taken from the National Drinking Water Clearinghouse. *Tech Brief*, “Water Hammer.”

Water hammer is the momentary increase in pressure that occurs in a water system when there is a sudden change of direction or velocity of the water. When a rapidly closed valve suddenly stops water flowing in a pipeline, pressure energy is transferred to the valve and pipe wall. Shock waves are set up within the system. Pressure waves travel backward until encountering the next solid obstacle, then forward, then back again. The pressure wave’s velocity is equal to the speed of the sound; therefore it “bangs” as it travels back and forth, until dissipated by friction losses. Anyone who has lived in an older house is familiar with the “bang” that resounds through the pipes when a faucet is suddenly closed. This is an effect of water hammer.

A less severe form of hammer is called surge; a slow motion, mass oscillation of water caused by internal pressure fluctuations in the system. This can be pictured as a slower “wave” of pressure building within the system. Water hammer and surge are referred to as transient pressures. If not controlled, they yield the same results: damage to pipes, fittings, and valves, causing leaks and shortening the life of the system. Neither the pipe nor the water will compress to absorb the shock.

Hydrostatic Test Pressure

The following is taken from Wikipedia, “Hydrostatic Test.”

A hydrostatic test is a way in which pressure vessels such as pipelines, plumbing, gas cylinders, boilers, and fuel tanks can be tested for strength and leaks. The test involves filling the vessel or pipe system with a liquid, usually water, which may be dyed to aid in visual leak detection, and pressurization of the vessel to the specified test pressure. Pressure tightness can be tested by shutting off the supply valve and observing whether there is a pressure loss. The location of a leak can be visually identified more easily if the water contains a colorant. Strength is usually tested by measuring permanent deformation of the container. Hydrostatic testing is the most common method employed for testing pipes and pressure vessels. Using this test helps maintain safety standards and durability of a vessel over time. Newly manufactured pieces are initially qualified using the hydrostatic test. They are then re-qualified at regular intervals using the proof pressure test which is also called the modified hydrostatic test. Testing of pressure vessels for transport and storage of gases is very important because such containers can explode if they fail under pressure.

Laminar Flow

The following is taken from DOE-HDBK-1012/3-92.

Laminar flow is also referred to as streamline or viscous flow. These terms are descriptive of the flow because in laminar flow 1) layers of water flow over one another at different speeds with virtually no mixing between layers; 2) fluid particles move in definite and observable paths or streamlines; and 3) the flow is characteristic of viscous (thick) fluid or is one in which viscosity of the fluid plays a significant part.

Turbulent Flow

The following is taken from DOE-HDBK-1012/3-92.

Turbulent flow is characterized by the irregular movement of particles of the fluid. There is no definite frequency as there is in wave motion. The particles travel in irregular paths with no observable pattern and no definite layers.

b. Discuss the potential hazards associated with water hammer and how personnel and equipment may be affected.

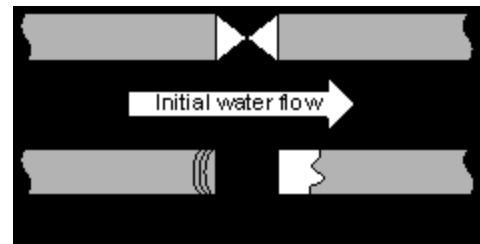
The following is taken from DOE/EH-0560.

Water hammer, also known as steam hammer, is a pressure or momentum transient in a closed system caused by a rapid change in fluid velocity. It is classified according to the cause of the velocity change.

The types of water hammer include the following:

- Valve-induced water hammer
- Void-induced water hammer
- Flashing-induced water hammer
- Steam-propelled water slug
- Condensate-induced water hammer

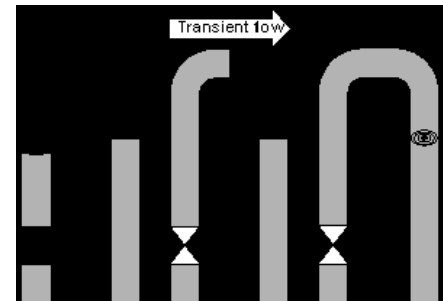
Valve-induced water hammer occurs when a valve is closed suddenly. This causes pressure waves to propagate through the water in the upstream direction from the valve. Suddenly closing a valve can also result in a temporary void downstream of the valve. When the void collapses, it causes pressure waves to propagate through the water in the downstream direction from the valve. This is shown in figure 39.



Source: DOE/EH-0560

Figure 39. Valve-induced water hammer

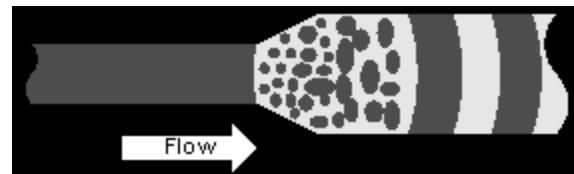
Void-induced water hammer occurs when a line refills after a void has formed, usually as a result of a suction break. When a valve is opened, admitting water to the line, the newly admitted water fills the void until it impacts the remaining water. This impact causes a pressure wave that propagates in both directions. This process is shown in figure 40.



Source: DOE/EH-0560

Figure 40. Void-induced water hammer

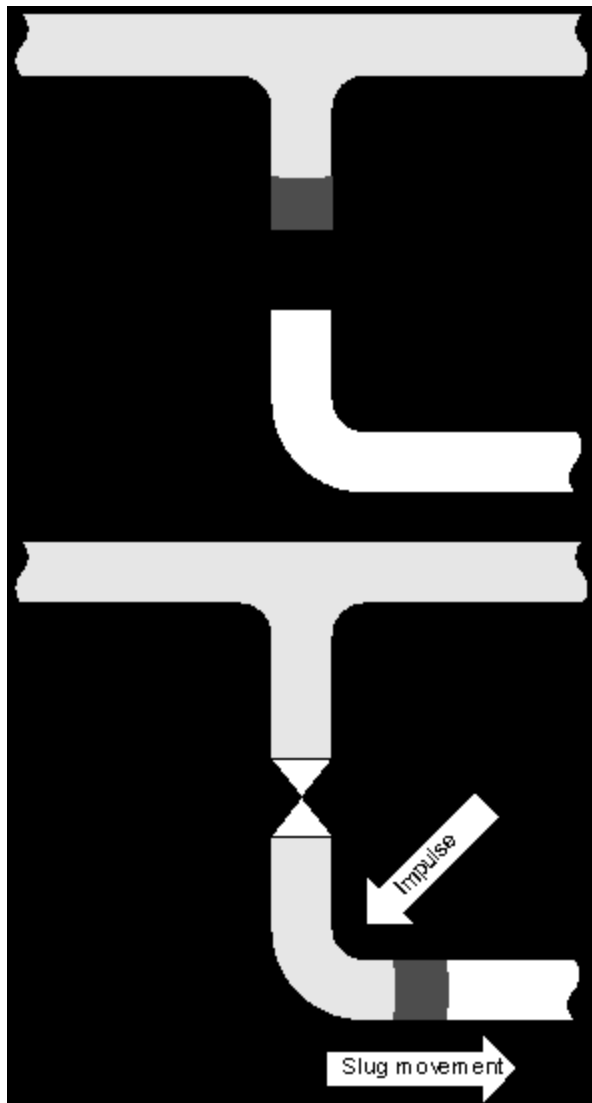
Flashing-induced water hammer can occur when water moves through a pressure drop to a region where the pressure is less than the vapor pressure of the water. Some water will turn to steam, cooling the mixture until the steam pressure is equal to the ambient pressure. The expansion of the steam propels the water forward and can compress it into slugs, as shown in figure 41. When a slug impacts standing water or encounters a piping change, it generates a pressure wave or momentum transient.



Source: DOE/EH-0560

Figure 41. Flash-induced water hammer

A steam-propelled water slug can occur when a steam valve is opened, causing a pressure difference across a water slug. This difference accelerates the slug, which causes transients when the slug changes speed or direction, such as the outward impulse to an elbow, as shown in figure 42. Because this type of water hammer causes momentum impulses instead of pressure waves, it tends to damage piping supports.

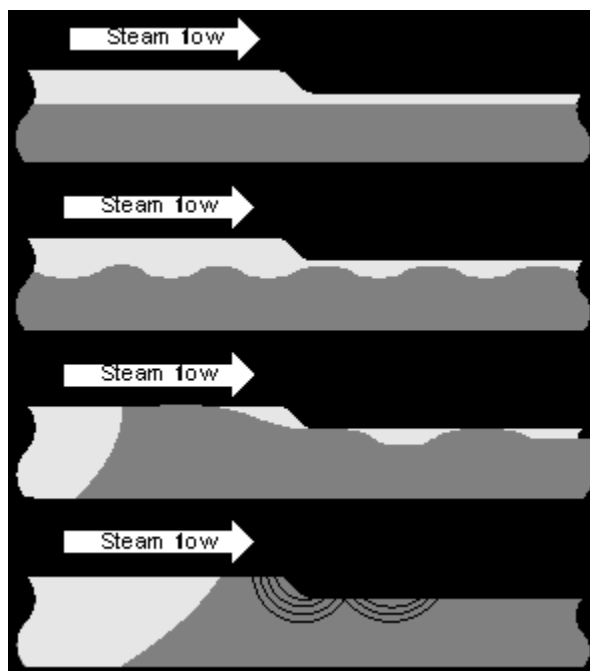


Source: DOE/EH-0560

Figure 42. Water Hammer from Steam-propelled Water Slug

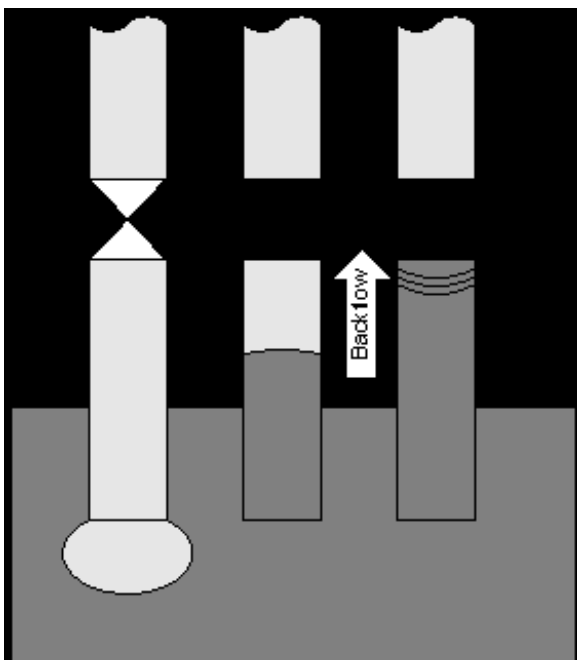
Condensate-induced water hammer is caused by rapid condensation of steam by subcooled water. It can occur in several different ways. The most common condensate-induced water hammer is caused by steam flowing over subcooled water. The steam flow causes ripples in the water surface. If one of these ripples touches the top of the pipe, it can momentarily seal off a pocket of steam, which then condenses and collapses, causing a pressure wave. This is shown in figure 43.

Condensate-induced water hammer causes the most severe water-hammer accidents and was the cause of three fatalities at DOE facilities.



Source: DOE/EH-0560

Figure 43. Condensate-induced water hammer in a horizontal pipe



Source: DOE/EH-0560

Figure 44. Water canon

Another type of condensate-induced water hammer occurs when the flow of steam into subcooled water stops suddenly, e.g., by closing a valve. This is referred to as a water canon. The remaining steam in the line condenses, drawing the subcooled water back into the line. When this water impacts the closed valve, a pressure wave is generated. This process is shown in figure 44.

Condensate-induced water hammer is the most frequently reported type of water hammer at DOE facilities and was the cause of all of the fatalities and injuries and most of the monetary damage attributed to water hammer.

c. Identify and discuss the typical causes of water hammer in piping systems.

The following is taken from the National Drinking Water Clearinghouse. *Tech Brief*, “Water Hammer.”

A water transport system’s operating conditions are almost never at a steady state. Pressures and flows change continually as pumps start and stop, demand fluctuates, and tank levels change. In addition to these normal events, unforeseen events, such as power outages and equipment malfunctions, can sharply change the operating conditions of a system. Any change in liquid flow rate, regardless of the rate or magnitude of change, requires that the liquid be accelerated or decelerated from its initial flow velocity. Rapid changes in flow rate require large forces that are seen as large pressures, which cause water hammer.

Entrained air or temperature changes of the water also can cause excess pressure in the water lines. Air trapped in the line will compress and will exert extra pressure on the water. Temperature changes will actually cause the water to expand or contract, also affecting pressure. The maximum pressures experienced in a piping system are frequently the result of vapor column separation, which is caused by the formation of void packets of vapor when pressure drops so low that the liquid boils or vaporizes. Damaging pressures can occur when these cavities collapse. The causes of water hammer are varied. There are, however, four common events that typically induce large changes in pressure:

1. Pump startup can induce the rapid collapse of a void space that exists downstream from a starting pump. This generates high pressures.
2. Pump power failure can create a rapid change in flow, which causes a pressure upsurge on the suction side and a pressure downsurge on the discharge side. The downsurge is

usually the major problem. The pressure on the discharge side reaches vapor pressure, resulting in vapor column separation.

3. Valve opening and closing is fundamental to safe pipeline operation. Closing a valve at the downstream end of a pipeline creates a pressure wave that moves toward the reservoir. Closing a valve in less time than it takes for the pressure surge to travel to the end of the pipeline and back is called “sudden valve closure.” Sudden valve closure will change velocity quickly and can result in a pressure surge. The pressure surge resulting from a sudden valve opening is usually not as excessive.
4. Improper operation or incorporation of surge protection devices can do more harm than good. An example is oversizing the surge relief valve or improperly selecting the vacuum breaker/air relief valve. Another example is trying to incorporate some means of preventing water hammer when it may not be a problem.

d. Discuss the purpose of seismic restraints (whip restraints or snubbers) in piping systems.

The following is taken from *HVAC Principles and Application Manual*, Thomas E. Mull.

The main intent of seismic restraints is to prevent non-structural items in a building, such as HVAC equipment, from becoming lethal missiles in the event of an earthquake. Earthquakes can cause equipment to break loose and fall from a ceiling or slide across a floor when the ground shakes a building and its contents. In addition to the lethal missile problem, it is also important to keep building mechanical systems in operation during and after an earthquake. The attachment (or seismic restraint) of equipment must have sufficient strength to transmit the forces during an earthquake, or it must provide sufficient isolation to allow for the induced motion of the equipment.

There are two general methods for restraining equipment such as HVAC and other mechanical equipment. The first method is to rigidly attach the equipment to the building structure to prevent any movement. In such an arrangement, the supporting members used to attach the equipment to the building structure must be strong enough to withstand the forces that would be expected in the event of an earthquake. Rigidly attaching equipment to the building structure has some disadvantages. The second method is the isolation approach, in which equipment is provided with sufficient space and the support has sufficient flexibility to reduce the possibility of excessive motion of the equipment. This method usually employs restraints to limit the travel of the equipment.

e. Describe the principle of operation for the various methods of measuring piping system parameters (e.g., pressure, temperature, flow), including the following:

- Resistance temperature detector (RTD)
- Differential pressure detector
- Pitot tube
- Thermocouple
- Bourdon tube pressure gauge
- Duplex pressure gauge
- Manometer
- Mechanical flowmeters
- Orifice flowmeters

Resistance Temperature Detector

The following is taken from Temperatures.com, “Resistance Temperature Detectors.”

Resistance temperature detectors (RTDs) are wire wound and thin film devices that measure temperature due to the physical principle of the positive temperature coefficient of electrical resistance of metals.

The hotter they become, the larger or higher the value of their electrical resistance.

Platinum RTDs known as PRTs and PRT100s are the most popular RTD type, nearly linear over a wide range of temperatures and some small enough to have response times of a fraction of a second.

They are among the most precise temperature sensors available with resolution and measurement uncertainties of $\pm 0.1^\circ\text{C}$ or better possible in special designs.

Usually they are provided encapsulated in probes for temperature sensing and measurement with an external indicator, controller or transmitter, or enclosed inside other devices where they measure temperature as a part of the device’s function, such as a temperature controller or precision thermostat.

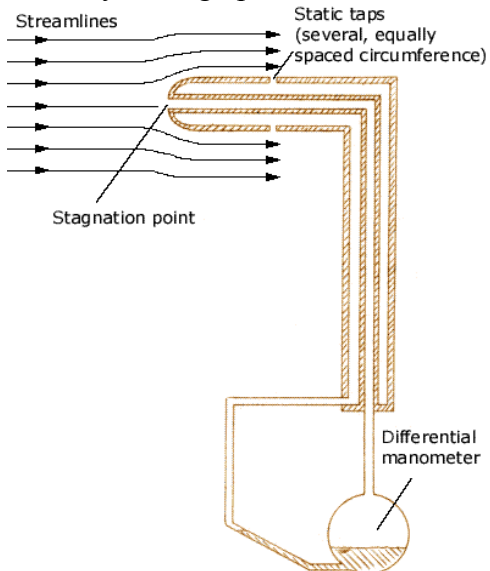
Video 31. Resistance temperature detectors

<http://www.bing.com/videos/search?q=resistance+temperature+detectors&view=detail&mid=C4591EA0464541A79408C4591EA0464541A79408&first=0>

Differential Pressure Detector

The following is taken from DOE-HDBK-1013/1-92.

The differential pressure (ΔP) detector method of liquid level measurement uses a ΔP detector connected to the bottom of the tank being monitored. The higher pressure, caused by the fluid in the tank, is compared to a lower reference pressure (usually atmospheric). This comparison takes place in the ΔP detector. The tank is open to the atmosphere; therefore, it is necessary to use only the high pressure connection on the ΔP transmitter. The low pressure side is vented to



the atmosphere; therefore, the pressure differential is the hydrostatic head, or weight, of the liquid in the tank. The maximum level that can be measured by the ΔP transmitter is determined by the maximum height of liquid above the transmitter. The minimum level that can be measured is determined by the point where the transmitter is connected to the tank.

Pitot Tube

The following is taken from eFunda. “Theory of Pitot-Static Tubes.”

The Pitot tube (named after Henri Pitot in 1732) measures a fluid velocity by converting the kinetic energy of the flow into potential energy. The conversion takes place at the stagnation point, located at the Pitot tube entrance (see figure 45). A pressure higher than the

Source: eFunda. Theory of Pitot Static Tubes

Figure 45. Cross-section of a typical pitot static tube

free-stream pressure results from the kinematic to potential conversion. This static pressure is measured by comparing it to the flow's dynamic pressure with a differential manometer.

Converting the resulting differential pressure measurement into a fluid velocity depends on the particular fluid flow regime the Pitot tube is measuring. Specifically, one must determine whether the fluid regime is incompressible, subsonic compressible, or supersonic.

Video 32. Pitot static tube

<http://vimeo.com/27159927>

Thermocouple

The following is taken from Wikipedia, "Thermocouples."

A thermocouple consists of two conductors of different materials that produce a voltage in the vicinity of the point where the two conductors are in contact. The voltage produced is dependent on, but not necessarily proportional to, the difference of temperature of the junction to other parts of those conductors. Thermocouples are a widely used type of temperature sensor for measurement and control and can also be used to convert a temperature gradient into electricity. They are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self-powered and require no external form of excitation. The main limitation of thermocouples is accuracy; system errors of less than one degree Celsius can be difficult to achieve.

Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple. Where the measurement point is far from the measuring instrument, the intermediate connection can be made by extension wires which are less costly than the materials used to make the sensor. Thermocouples are usually standardized against a reference temperature of 0 degrees Celsius; practical instruments use electronic methods of cold-junction compensation to adjust for varying temperature at the instrument terminals. Electronic instruments can also compensate for the varying characteristics of the thermocouple, and so improve the precision and accuracy of measurements.

Thermocouples are widely used in science and industry; applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes.

Video 33. Thermocouples

<http://wn.com/Thermocouple#/videos>

Bourdon Tube Pressure Gauge

The following is taken from Wikipedia, "Pressure Measurement."

The Bourdon pressure gauge uses the principle that a flattened tube tends to straighten or regain its circular form when pressurized. Although this change in cross-section may be hardly noticeable, and thus involving moderate stresses within the elastic range of easily workable materials, the strain on the material of the tube is magnified by forming the tube into a C shape or even a helix, such that the entire tube tends to straighten out or uncoil, elastically, as it is pressurized.

In practice, a flattened, thin-wall, closed-end tube is connected at the hollow end to a fixed pipe containing the fluid pressure to be measured. As the pressure increases, the closed end moves in an arc, and this motion is converted into the rotation of a gear by a connecting link that is usually adjustable. A small-diameter pinion gear is on the pointer shaft, so the motion is magnified further by the gear ratio. The positioning of the indicator card behind the pointer, the initial pointer shaft position, the linkage length, and initial position, all provide means to calibrate the pointer to indicate the desired range of pressure for variations in the behavior of the Bourdon tube itself. Differential pressure can be measured by gauges containing two different Bourdon tubes, with connecting linkages.

Bourdon tubes measure gauge pressure, relative to ambient atmospheric pressure, as opposed to absolute pressure; vacuum is sensed as a reverse motion. Some aneroid barometers use Bourdon tubes closed at both ends. When the measured pressure is rapidly pulsing, such as when the gauge is near a reciprocating pump, an orifice restriction in the connecting pipe is frequently used to avoid unnecessary wear on the gears and provide an average reading; when the whole gauge is subject to mechanical vibration, the entire case, including the pointer and indicator card, can be filled with an oil or glycerin. Tapping on the face of the gauge is not recommended as it will tend to falsify actual readings initially presented by the gauge. The Bourdon tube is separate from the face of the gauge and thus has no effect on the actual reading of pressure. Typical high-quality modern gauges provide an accuracy of ± 2 percent of span, and a special high-precision gauge can be as accurate as 0.1 percent of full scale.

Video 34. Bourdon tube

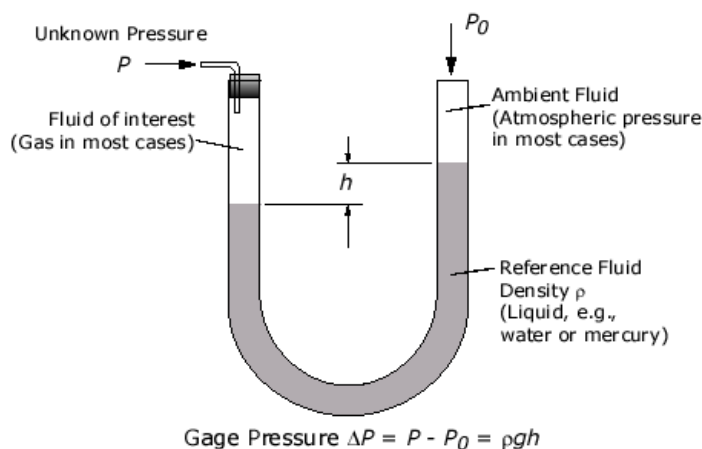
<http://www.bing.com/videos/search?q=bourdon+tube&view=detail&mid=F1729ABE1EB16812107AF1729ABE1EB16812107A&first=0>

Duplex Pressure Gauge

The following is taken from Floyd Instruments, “Duplex Pressure Gauges.”

The duplex gauge is most commonly known as a dual pressure gauge, consisting of two independent bourdon tube systems with two independent pointers within the one gauge.

Various uses within the general industry are for reading differential pressures across filters, orifice plates, etc., and more commonly on rail transport braking systems. Duplex gauges can also be a big advantage when installed in panels due to the space savings of using only one gauge instead of two. Dials can be produced as single scale, dual, or even with two different scale ranges. Special markings such as colored bands, lines, or sectors may also be offered.



Source: eFunda, Manometer Pressure

Figure 46. Manometer

Manometer

The following is taken from eFunda, “Manometer Pressure.”

Manometers measure a pressure difference by balancing the weight of a

fluid column between the two pressures of interest. Large pressure differences are measured with heavy fluids, such as mercury. Small pressure differences, such as those experienced in experimental wind tunnels or venturi flowmeters, are measured with lighter fluids such as water.

The pressure difference between the bottom and top of an incompressible fluid column is given by the incompressible fluid statics equation,

$$\Delta p = \rho gh$$

where g is the acceleration of gravity (9.81 meters/second²).

Video 35. Manometer

<http://www.bing.com/videos/search?q=manometer&view=detail&mid=596205DD717B5FCA0F71596205DD717B5FCA0F71&first=0>

Mechanical Flowmeters

The following is taken from Omega, “Flow and Level Measurement.”

All positive displacement flowmeters operate by isolating and counting known volumes of a fluid while feeding it through a meter. By counting the number of passed isolated volumes, a flow measurement is obtained. Each positive displacement (PD) design uses a different means of isolating and counting these volumes. The frequency of the resulting pulse train is a measure of flow rate, while the total number of pulses gives the size of the batch. While PD meters are operated by the kinetic energy of the flowing fluid, metering pumps determine the flow rate while also adding kinetic energy to the fluid.

The turbine flowmeter consists of a multi-bladed rotor mounted at right angles to the flow, suspended in the fluid stream on a free-running bearing. The diameter of the rotor is very close to the inside diameter of the metering chamber, and its speed of rotation is proportional to the volumetric flow rate. Turbine rotation can be detected by solid state devices or by mechanical sensors. Other types of rotary element flowmeters include the propeller (impeller), shunt, and paddlewheel designs.

POSITIVE DISPLACEMENT FLOWMETERS

PD meters provide high accuracy and good repeatability. Accuracy is not affected by pulsating flow unless it entrains air or gas in the fluid. PD meters do not require a power supply for their operation and do not require straight upstream and downstream pipe runs for their installation. PD meters are available in sizes from ¼-in to 12-in and can operate with turndowns as high as 100:1, although ranges of 15:1 or lower are much more common. Slippage between the flowmeter components is reduced and metering accuracy is therefore increased as the viscosity of the process fluid increases.

The process fluid must be clean. Particles greater than 100 microns in size must be removed by filtering. PD meters operate with small clearances between their precision-machined parts; wear rapidly destroys their accuracy. For this reason, PD meters are generally not recommended for measuring slurries or abrasive fluids. In clean fluid services, however, their precision and wide rangeability make them ideal for custody transfer and batch charging. They are most widely used as household water meters. Millions of such units are produced annually at a unit cost of less than \$50 U.S. In industrial and petrochemical applications, PD meters are commonly used for batch charging of both liquids and gases.

Although slippage through the PD meter decreases as fluid viscosity increases, pressure drop through the meter also rises. Consequently, the maximum flow capacity of the flowmeter is decreased as viscosity increases. The higher the viscosity, the less slippage and the lower the measurable flow rate becomes. As viscosity decreases, the low flow performance of the meter deteriorates. The maximum allowable pressure drop across the meter constrains the maximum operating flow in high viscosity services.

LIQUID PD METERS

Nutating disc meters are the most common PD meters. They are used as residential water meters around the world. As water flows through the metering chamber, it causes a disc to wobble (nutate), turning a spindle, which rotates a magnet. This magnet is coupled to a mechanical register or a pulse transmitter. Because the flowmeter entraps a fixed quantity of fluid each time the spindle is rotated, the rate of flow is proportional to the rotational velocity of the spindle.

Because it must be nonmagnetic, the meter housing is usually made of bronze but can be made from plastic for corrosion resistance or cost savings. The wetted parts such as the disc and spindle are usually bronze, rubber, aluminum, neoprene, Buna-N, or a fluoroelastomer. Nutating disc meters are designed for water service and the materials of which they are made must be checked for compatibility with other fluids. Meters with rubber discs give better accuracy than metal discs due to the better sealing they provide.

Nutating disc meters are available in $\frac{5}{8}$ -in to 2-in sizes. They are suited for 150-psig operating pressures with overpressure to a maximum of 300 psig. Cold water service units are temperature-limited to 120°F. Hot water units are available up to 250°F.

These meters must meet American Water Works Association (AWWA) standards for accuracy. The accuracy of these meters is required to be ± 2 percent of actual flow rate. Higher viscosity can produce higher accuracy, while lower viscosity and wear over time will reduce accuracy. The AWWA requires that residential water meters be re-calibrated every 10 years. Because of the intermittent use patterns of residential users, this corresponds to recalibrating $\frac{5}{8}$ - x $\frac{3}{4}$ -in residential water meters after they have metered 5 million gallons. In industrial applications, however, these meters are likely to pass this threshold much sooner. The maximum continuous flow of a nutating disc meter is usually about 60-80 percent of the maximum flow in intermittent service.

Rotating vane meters have spring-loaded vanes that entrap increments of liquid between the eccentrically mounted rotor and the casing. The rotation of the vanes moves the flow increment from inlet to outlet and discharge. Accuracy of ± 0.1 percent of actual rate (AR) is normal, and larger size meters on higher viscosity services can achieve accuracy to within 0.05 percent of rate.

Rotating vane meters are regularly used in the petroleum industry and are capable of metering solids-laden crude oils at flow rates as high as 17,500 gallons per minute (gpm). Pressure and temperature limits depend on the materials of construction and can be as high as 350°F and 1,000 psig. Viscosity limits are 1 to 25,000 centipoise.

In the rotary displacement meter, a fluted central rotor operates in constant relationship with two wiper rotors in a six-phase cycle. Its applications and features are similar to those of the rotary vane meter.

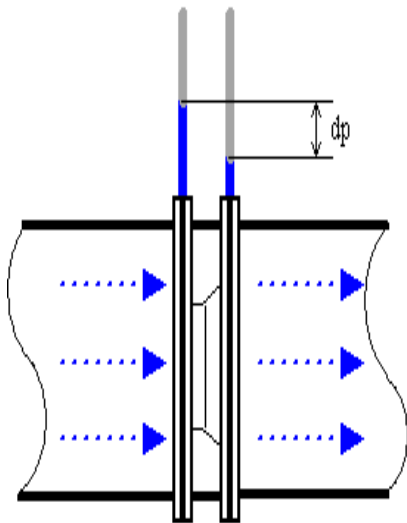
PISTON FLOWMETERS

Oscillating piston flowmeters typically are used in viscous fluid services such as oil metering on engine test stands where turndown is not critical. These meters also can be used on residential water service and can pass limited quantities of dirt, such as pipe scale and fine sand but not large particle size or abrasive solids.

The measurement chamber is cylindrical with a partition plate separating its inlet port from its outlet. The piston is also cylindrical and is punctured by numerous openings to allow free flow on both sides of the piston and the port. The piston is guided by a control roller within the measuring chamber, and the motion of the piston is transferred to a follower magnet which is external to the flowstream. The follower magnet can be used to drive either a transmitter, a register, or both. The motion of the piston is oscillatory (not rotary) since it is constrained to move in one plane. The rate of flow is proportional to the rate of oscillation of the piston.

The internals of this flowmeter can be removed without disconnection of the meter from the pipeline. Because of the close tolerances required to seal the piston and to reduce slippage, these meters require regular maintenance. Oscillating piston flow meters are available in ½-in to 3-in sizes, and can generally be used between 100 and 150 psig. Some industrial versions are rated to 1,500 psig. They can meter flow rates from 1 gpm to 65 gpm in continuous service with intermittent excursions to 100 gpm. Meters are sized so that pressure drop is below 35 psid at maximum flow rate. Accuracy ranges from ± 0.5 percent AR for viscous fluids to ± 2 percent AR for nonviscous applications. Upper limit on viscosity is 10,000 centipoise.

Reciprocating piston meters are probably the oldest PD meter designs. They are available with multiple pistons, double-acting pistons, or rotary pistons. As in a reciprocating piston engine, fluid is drawn into one piston chamber as it is discharged from the opposed piston in the meter. Typically, either a crankshaft or a horizontal slide is used to control the opening and closing of the proper orifices in the meter. These meters are usually smaller and are used for measuring very low flows of viscous liquids.



The Engineering ToolBox, Orifice, Nozzle, and Venturi Flow Rate Meters

Figure 47. Orifice flowmeter

Orifice Flowmeters

The following is taken from The Engineering ToolBox, “Orifice, Nozzle, and Venturi Flow Rate Meters.”

The orifice meter consists of a flat orifice plate with a circular hole drilled in it. There is a pressure tap upstream from the orifice plate and another just downstream. There are in general three methods of placing the taps. The coefficient of the meter depends on the position of taps.

1. Flange location—Tap location 1 inch upstream and 1 inch downstream from face of orifice

2. “Vena Contracta” location—Tap location 1 pipe diameter (actual inside) upstream and 0.3 to 0.8 pipe diameter downstream from face of orifice
3. Pipe location—Tap location 2.5 times nominal pipe diameter upstream and 8 times nominal pipe diameter downstream from face of orifice

The discharge coefficient c_d varies considerably with changes in area ratio and the Reynolds number. A discharge coefficient $c_d = 0.60$ may be taken as standard, but the value varies noticeably at low values of the Reynolds number.

The pressure recovery is limited for an orifice plate and the permanent pressure loss depends primarily on the area ratio. For an area ratio of 0.5, the head loss is about 70-75 percent of the orifice differential.

- The orifice meter is recommended for clean and dirty liquids and some slurry services.
- The rangeability is 4 to 1.
- The pressure loss is medium.
- Typical accuracy is 2 to 4 percent of full scale.
- The required upstream diameter is 10 to 30.
- The viscosity effect is high.
- The relative cost is low.

f. Identify and discuss different methods of pipe joining (threaded, butt weld, socket weld, seal weld, etc.)

Threaded Joints

The following is taken from Wikipedia, “Threaded Pipe.”

The threaded pipes used in some plumbing installations for the delivery of gases or fluids under pressure have a threaded section that is slightly conical. This is called a tapered thread. The seal provided by a threaded pipe joint depends on the labyrinth seal created by the threads; upon a positive seal between the threads created by the deformation of the threads when they are tightened to the proper torque; and sometimes on the presence of a sealing coating, such as thread seal tape, or a liquid or paste pipe sealant such as pipe dope. Tapered thread joints typically do not include a gasket.

Especially precise threads are known as dry fit or dry seal meaning that no sealant is required for a gas-tight seal. Such threads are needed where the sealant would contaminate or react with the media inside the piping, e.g., oxygen service.

Tapered threaded fittings are sometimes used on plastic piping. Due to the wedging effect of the tapered thread, extreme care must be used to avoid over-tightening the joint. The over-stressed female fitting may split days, weeks, or even years after initial installation. Therefore many municipal plumbing codes restrict the use of threaded plastic pipe fittings.

Pipes may also be threaded with cylindrical threaded sections, in which case the threads do not themselves provide any sealing function other than some labyrinth seal effect, which may not be enough to satisfy either functional or code requirements. With straight pipe threads, the seal may be provided by an O-ring seated between the shoulder of the male pipe section and an interior surface on the female part.

Butt Welded Joints

The following is taken from Wikipedia, “Welding Joints.”

Butt welds are welds where two pieces of metal are joined at surfaces that are at 90 degree angles to the surface of at least one of the other pieces. These types of welds require only some preparation and are used with thin sheet metals that can be welded with a single pass. Common issues that can weaken a butt weld are the entrapment of slag, excessive porosity, or cracking. For strong welds, the goal is to use the least amount of welding material possible. Butt welds are prevalent in automated welding processes, such as submerged-arc welding, due to their relative ease of preparation. When metals are welded without human guidance, there is no operator to make adjustments for non-ideal joint preparation. Because of this necessity, butt welds can be used for their simplistic design to be fed through automated welding machines efficiently.

There are many types of butt welds, but all fall within one of these categories: single welded butt joints, double welded butt joints, and open or closed butt joints. A single welded butt joint is the name for a joint that has only been welded from one side. A double welded butt joint is created when the weld has been welded from both sides. With double welding, the depths of each weld can vary slightly. A closed weld is a type of joint in which the two pieces that will be joined are touching during the welding process. An open weld is the joint type where the two pieces have a small gap in between them during welding.

SQUARE BUTT JOINTS

The square-groove is a butt welding joint with the two pieces being flat and parallel to each other. This joint is simple to prepare, economical to use, and provides satisfactory strength, but is limited by joint thickness. The closed square butt weld is a type of square-groove joint with no spacing in between the pieces. This joint type is common with gas and arc welding.

For thicker joints, the edge of each member of the joint must be prepared to a particular geometry to provide accessibility for welding and to ensure the desired weld soundness and strength. The opening or gap at the root of the joint and the included angle of the groove should be selected to require the least weld metal necessary to give needed access and meet strength requirements.

BEVEL BUTT JOINTS

Single-bevel butt welds are welds where one piece in the joint is beveled and the other surface is perpendicular to the plane of the surface. These types of joints are used where adequate penetration cannot be achieved with a square-groove and the metals are to be welded in the horizontal position. Double-bevel butt welds are common in arc and gas welding processes. In this type both sides of one of the edges in the joint are beveled.

V-JOINTS

Single-V butt welds are similar to a bevel joint, but instead of only one side having the beveled edge, both sides of the weld joint are beveled. In thick metals, and when welding can be performed from both sides of the work piece, a double-V joint is used. When welding thicker metals, a double-V joint requires less filler material because there are two narrower V-joints compared to a wider single-V joint. Also the double-V joint helps compensate for warping forces. With a single-V joint, stress tends to warp the piece in one direction when the V-joint is

filled, but with a double-V-joint, there are welds on both sides of the material, having opposing stresses, straightening the material.

J-JOINTS

Single-J butt welds are when one piece of the weld is in the shape of a J that easily accepts filler material and the other piece is square. A J-groove is formed either with special cutting machinery or by grinding the joint edge into the form of a J. Although a J-groove is more difficult and costly to prepare than a V-groove, a single J-groove on metal between a half an inch and three quarters of an inch thick provides a stronger weld that requires less filler material. Double-J butt welds have one piece that has a J shape from both directions and one piece that is square.

U-JOINTS

Single-U butt welds are welds in which both edges of the weld surface are shaped like a J, but once they come together, they form a U. Double-U joints have a U formation on both the top and bottom of the prepared joint. U-joints are the most expensive edge to prepare and weld. They are usually used on thick base metals where a V-groove would be at such an extreme angle that it would cost too much to fill.

Socket Weld

The following is taken from eHow, “Butt Weld Vs. Socket Weld.”

A socket weld involves two different sized pieces of pipe. The smaller pipe is inside the larger pipe. The weld is completely around the outside circumference of the larger pipe.

Seal Weld

The following is taken from WiseGeek, “What is a Seal Weld?”

A seal weld is a weld that performs the primary function of sealing joints. Seal welds are commonly used in gas or liquid containers to contain the gaseous or liquid substances and to prevent leakage. The presence of seal welds also prevents the gases or fluids from entering specific, off-limits areas where they may cause corrosion or other damage.

Seal welds are applied to parts that are to be galvanized. There are two types of ready-to-be galvanized joints, regular and vented, that can be welded together respectively with seal welding; there is also a third ready-to-be galvanized joint that does not require a seal weld. With regular joints, care must be taken to ensure that the seal welds are not so porous as to allow any kind of leakage. Vented joints are joints that have vents or holes in them to allow gas to escape out. When applying seal welds to vented joints, it is important to ensure that the vents are placed in proper locations; otherwise, a build-up of gas might damage the joints.

g. Discuss the purpose and types of freeze protection measures used in piping systems.

The following is taken from Bollinger Insurance, “Preventing Fire Sprinkler Freeze-ups.”

Cold weather brings the danger of impaired fire protection because of water freezing in sprinkler piping and other system components. Frozen fire protection systems result in not only fire losses due to crippled detection or extinguishing systems, but also extensive water damage to the building and contents resulting from burst piping. The breaking of piping, valves, and inevitable water damage as a result of frozen piping usually occurs when temperatures once

again rise above freezing and the ice begins to thaw. Automatic sprinkler system freeze-ups occur when insufficient heat is provided to a building either by a shutdown of the heating system, cold air coming through broken windows, cracks in a wall, insufficient insulation material in ceilings/walls, inadequate antifreeze in a loop section of the system, and other physical deficiencies. Though losses occur as the result of extreme cold conditions, losses occur more frequently in climates that are not normally associated with cold weather when unexpected cold fronts impact the area. It is important that maintenance physically inspect all buildings and any areas protected by automatic sprinkler protection before the cold weather season arrives. This is to insure that there are no areas with insufficient heat and that physical features and precautions are in place to insure that susceptible elements of the system are not exposed to cold weather.

GENERAL PRECAUTIONS

The following preventive measures should be considered prior to and during cold weather season:

- Have employees keep alert for and report potential or existing cold weather problems.
- Check fire protection systems more frequently than normal during cold weather.
- Do not attempt do-it-yourself repairs on fire safety equipment. Rather obtain the services of trained service personnel.
- Do not use torches or other open flame devices to thaw pipes or other equipment.
- The use of temporary heating equipment, such as salamanders and other un-vented, portable fuel-burning heaters, is not recommended as these heaters introduce fire and health hazards. Portable electric heaters also present unnecessary fire and health hazards. It is suggested that existing heating systems be extended or upgraded where possible.
- Do not store excessive quantities of fuel or flammable liquids in areas not designed for that purpose.
- During the annual servicing of the sprinkler system by the contractor, have them demonstrate the operation of all valves. Have appropriate personnel rehearse closing the valves so they can shut down the system in the event of a burst pipe.
- Water supplies and fire pumps should be kept from freezing.
- Plan to remove snow from fire hydrants, post indicator valves, and fire department pumper connections.

The following procedures and safeguards will help prevent wet pipe systems from freezing during cold weather.

WET PIPE SYSTEMS

Freezing of wet pipe (water normally in the piping at all times) sprinkler systems occurs most often due to a lack of adequate heat; however, open doors, windows, and vents; broken windows; cracks in walls; loose shingles and siding; and similar building maintenance defects are also responsible for a number of frozen systems each year.

- Keep doors, windows and vents closed when not in use or when resulting drafts will allow subfreezing air to contact sprinkler piping. Repair broken windows, doors, and other items in need of fixing. Remember the possibility that high winds may accompany periods of low temperatures.
- Where sprinkler piping may be exposed to outside temperatures, such as when it is run between two buildings, the pipe should be heated or adequately insulated.

- Provide heating of adequate capacity to maintain the temperature at no less than 40°F near sprinkler piping during the severest protracted cold spell that might reasonably be expected. Particular attention should be given to piping in attics, entries, penthouses, stairways, under floor areas, above ceilings, shipping areas, and similar out-of-the-way areas where low temperatures might occur. Heat should be provided by extension of the existing heating system. Where drop ceilings are used, removing a few strategically placed ceiling tiles will allow extra heat into the opened area during cold weather.
- If it is known that the sprinkler system is to be exposed to freezing temperatures, such as when a building or building section's heating system is planned to be shut off, or if heating is interrupted for more than a few hours, precautionary measures must be taken. The system's water may have to be drained and a fire watch established or temporary heating provided.
- For loading docks or other sections of the system that may have an antifreeze loop system, the specific gravity of the antifreeze solution must be checked prior to the cold weather season to ensure that it has the proper proportions of antifreeze and water.
- Make sure the valve is open.

DRY PIPE SYSTEMS

Dry pipe sprinkler systems, because they do not normally contain water in their piping, are less likely to freeze than wet pipe systems. Nonetheless, certain precautions should be taken to ensure that freezing does not become a problem in such sprinkler systems when cold weather arrives:

- Drain any water or condensate from auxiliary drains and all other low points. Do not forget the drains under the stairs or platforms. The use of a checklist is suggested.
- Be sure the dry pipe valve and riser on the water supply side of the valve are adequately protected against freezing. Heat the valve enclosure using electrical heater strips under thermostatic controls so that a minimum of 50°F can be maintained.
- Ascertain that sufficient air is in the system to allow for a drop in pressure that occurs under low temperatures; the pressure should be checked daily during cold weather or provide supervision of the pressure and low-pressure alarms. Inadequate pressure can result in the dry pipe valve tripping and subsequent freezing of the water that enters the system piping.
- Air is usually supplied to a dry pipe system by a compressor. The air intakes into the compressor should be located in a cold, dry atmosphere. Avoid warm, damp areas, since moisture introduced with the air condenses in the piping and collects at low points where it may freeze. Air dryers should be installed on the air intake.
- Repair, replace or refasten broken, missing or loose sprinkler pipe hangers to ensure proper pitch of sprinkler piping and to provide good drainage.
- A temperature-signaling device monitored by a central station alarm service can be installed in the valve room or enclosure.

12. Mechanical systems personnel shall demonstrate a working level knowledge of the general construction, operation, and theory of valves.

- a. **Define the following terms as they relate to valves:**
 - **Disc**
 - **Seat/backseat**

- **Throttle**
- **Actuator**
- **Bonnet**
- **Packing**

Disc

The following is taken from Wikipedia, “Valve.”

A disc or valve member is a movable obstruction inside the stationary body that adjustably restricts flow through the valve. Although traditionally disc-shaped, discs come in various shapes. Depending on the type of valve, a disc can move linearly inside a valve, or rotate on the stem, or rotate on a hinge or trunnion. A ball is a round valve member with one or more paths between ports passing through it. By rotating the ball, flow can be directed between different ports. Ball valves use spherical rotors with a cylindrical hole drilled as a fluid passage. Plug valves use cylindrical or conically tapered rotors called plugs. Other round shapes for rotors are possible as well in rotor valves, as long as the rotor can be turned inside the valve body. However, not all round or spherical discs are rotors; for example, a ball check valve uses the ball to block reverse flow, but is not a rotor because operating the valve does not involve rotation of the ball.

Seat

The following is taken from Wikipedia, “Valve.”

The seat is the interior surface of the body that contacts the disc to form a leak-tight seal. In discs that move linearly or swing on a hinge or trunnion, the disc comes into contact with the seat only when the valve is shut. In disks that rotate, the seat is always in contact with the disk, but the area of contact changes as the disc is turned. The seat always remains stationary relative to the body.

Seats are classified by whether they are cut directly into the body, or if they are made of a different material:

- Hard seats are integral to the valve body. Nearly all hard seated metal valves have a small amount of leakage.
- Soft seats are fitted to the valve body and made of softer materials such as PTFE or various elastomers such as NBR, EPDM, or FKM depending on the maximum.

A closed soft seated valve is much less liable to leak when shut while hard seated valves are more durable. Gate, globe, and check valves are usually hard seated while butterfly, ball, plug, and diaphragm valves are usually soft seated.

Throttle

The following is taken from Wikipedia, “Throttle.”

A throttle is the mechanism by which the flow of a fluid is managed by constriction or obstruction. An engine’s power can be increased or decreased by the restriction of inlet gases, but usually decreased. The term throttle has come to refer, informally and incorrectly, to any mechanism by which the power or speed of an engine is regulated. What is often termed a throttle is more correctly called a thrust lever. For a steam engine, the steam valve that sets the engine speed/power is often known as a regulator.

Actuator

The following is taken from Wikipedia, “Valve.”

An actuator is a mechanism or device to automatically or remotely control a valve from outside the body. Some valves have neither handle nor actuator because they automatically control themselves from inside; for example, check valves and relief valves may have neither.

Bonnet

The following is taken from Wikipedia, “Valve.”

A bonnet acts as a cover on the valve body. It is commonly semi-permanently screwed into the valve body or bolted onto it. During manufacture of the valve, the internal parts are put into the body and then the bonnet is attached to hold everything together inside. To access internal parts of a valve, a user would take off the bonnet, usually for maintenance. Many valves do not have bonnets; for example, plug valves usually do not have bonnets. Many ball valves do not have bonnets since the valve body is put together in a different style, such as being screwed together at the middle of the valve body.

Packing

The following is taken from YC Industries, “Valve Packing.”

The purpose of valve packing in a valve is to prevent the leakage of the media, either liquid or gas, in the valve to the exterior atmosphere past the stem of the valve. The valve packing is contained in the valve’s stuffing box.

b. Discuss why the design of a globe valve enables it to throttle fluids efficiently.

The following is taken from DOE-HDBK-1018/2-93.

The essential principle of globe valve operation is the perpendicular movement of the disc away from the seat. This causes the annular space between the disc and seat ring to gradually close as the valve is closed. This characteristic gives the globe valve good throttling ability, which permits its use in regulating flow.

c. Discuss why gate valves, ball valves, and butterfly valves should never be used to throttle flow.

The following is taken from DOE-HDBK-1018/2-93.

Because of the way gate valves, ball valves, and butterfly valves are designed, throttling with these valves would cause severe seat erosion and would lead to much quicker seating surface failure.

d. Discuss how cavitation occurs in valves and state any harmful effects that can result from cavitation.

The following is taken from WiseGeek, “What is Cavitation?”

Cavitation occurs in liquid when bubbles form and implode in pump systems or around propellers. Pumps put liquid under pressure, but if the pressure of the substance drops or its temperature increases, it begins to vaporize, just like boiling water. Yet in such a small, sensitive system, the bubbles can’t escape so they implode, causing physical damage to parts of the pump or propeller.

A combination of temperature and pressure constraints will result in cavitation in any system. No manufacturer or industrial technician wants to run pumps that keep getting affected by cavitation, as it will permanently damage the chambers of the device. The vaporization actually causes a loud, rocky noise because the bubbles are imploding and making the liquid move faster than the speed of sound!

Inside every pump, there is a propeller that draws liquid from one side of the chamber to the other. The liquid normally continues out through a valve so it can do another job in a different part of the machine. Sometimes this device is called an impeller. Even though the total chamber stays under the same pressure, and the materials are temperature regulated, cavitation manages to occur right next to the surface of the propeller.

A propeller rotates through a liquid and actually creates localized differences in pressure along the propeller blades. This can even occur underwater on a submarine or ship's propeller. The bubbles of cavitation appear in low-pressure areas but then immediately want to implode with such force that they make dings and pits in metal. A propeller exposed to cavitation resembles the surface of the moon, with tiny, scattered craters.

There are two types of cavitation that can occur in the different stages of pumping, but both are results of the same phenomenon. Suction or classical cavitation occurs around the impeller as it is drawing liquid through the chamber. The propeller's motion creates the changes in pressure necessary for vaporization.

Discharge or recirculation cavitation is the result of changing pressure at the point of exit, the discharge valve. The valve is not able to let all the liquid through as fast as it should, so the currents' different velocities create miniature changes in the uniform pressure. Even such small variations are enough to create the ideal circumstances for cavitation.

e. Describe the construction and principle of operation for the following types of valve actuators:

- **Manual**
- **Electric**
- **Solenoid**
- **Pneumatic**
- **Hydraulic**

Manual

The following is taken from Valvias, "Manual Actuators."

Manual actuation is done by a human driving force.

While the manual actuation can be made directly on the axis of the valve through a handwheel or other devices, manufacturers refer to manual actuator as incorporating a manual gearbox, a mechanism that provides greater torque based on more turns.

In fact, it is normal to couple gearboxes in electric or pneumatic actuators to increase their features, or at least supplement them with a manual driver in case of failure of the main source.

Manual actuation is usually driven by handwheels. Valves whose access location makes difficult to operate on them can be driven by



Source: Valvias, Manual Actuators

Figure 48.
Handwheel

chain wheels. For security, the driver can be removed from the gearbox spigot; then, only authorized operators who bring the handwheel or wrench nut with them can operate the valve.

Several norms indicate the maximum allowable effort applied on the manual driver by a person. The drive and gearbox as a whole must be dimensioned according to these norms. Some specifications indicate a maximum rim pull of 80 lb (356 N) on handwheels and chain wheels, and a maximum input of 150 lb·in (17 N·m) on wrench nuts.

Most of the valves require an operator torque that can only be achieved with a gearbox. There are part-turn and quarter-turn manual actuators.

Most of part-turn gearboxes are quarter-turn or 90° stroke plus a tolerance. The most extended mechanism is worm gear type. Butterfly and ball valves use these types of actuators.

Manual multi-turn gearboxes have no limit of turn, so they need a stop-limiting device. Spur and cylinder gear are common types of mechanisms. Globe and gate valves require this type of actuator.

Standards or specifications can also indicate a certain type of valve and the minimum or maximum number of turns that the valve would need to be operated.

Electric

The following is taken from Nuclear Exchange, “A Descriptive Definition of Valve Actuators.”

Electric multi-turn actuators—the electrically powered multi-turn actuators are one of the most common and dependable configurations of actuators. A single or three-phased electric motor drives a combination of spurs and/or level gears, which in turn drive a stem nut. The stem nut engages the stem of the valve to open or close it, frequently via an Acme threaded shaft. Electric multi-turn actuators are capable of quickly operating very large valves. To protect the valve, the limit switch turns off the motor at the ends of travel. The torque sensing mechanism of the actuator switches off the electric motor when a safe torque level is exceeded. Position indicating switches are used to indicate the open and closed position of the valve. Typically a declutching mechanism and hand wheel are included so that the valve can be operated manually should a power failure occur. The main advantage of this type of actuator is that all of the accessories are incorporated in the package and are physically and environmentally protected. It has all the basic and advance functions incorporated in a compact housing that can be water tight, explosion proof, and in some circumstances, submersible. The primary disadvantage of an electric multi-turn actuator is that, should a power failure occur, the valve remains in the last position and the fail-safe position cannot be obtained easily unless there is a convenient source of stored electrical energy.

Electric quarter-turn actuators—these units are very similar to an electric multi-turn actuator. The main difference is that the final drive element is usually in one quadrant that puts out a 90° motion. The newer generation of quarter-turn actuators incorporates many of the features found in most sophisticated multi-turn actuators; for example, a non-intrusive, infrared, human/machine interface for set up, diagnostics, etc. Quarter-turn electric actuators are compact and can be used on smaller valves. They are typically rated to around 1,500 foot pounds. An added advantage of a smaller quarter-turn actuators is that, because of their lower power requirements, they can be fitted with an emergency power source such as a battery to provide failsafe operation.

Solenoid

The following is taken from Wikipedia, “Solenoid.”

A solenoid is a coil wound into a tightly packed helix. In physics, the term solenoid refers to a long, thin loop of wire, often wrapped around a metallic core, which produces a magnetic field when an electric current is passed through it. Solenoids are important because they can create controlled magnetic fields and can be used as electromagnets. The term solenoid refers specifically to a coil designed to produce a uniform magnetic field in a volume of space.

In engineering, the term solenoid may also refer to a variety of transducer devices that convert energy into linear motion. The term is also often used to refer to a solenoid valve, which is an integrated device containing an electromechanical solenoid that actuates either a pneumatic or hydraulic valve, or a solenoid switch, which is a specific type of relay that internally uses an electromechanical solenoid to operate an electrical switch; for example, an automobile starter solenoid, or a linear solenoid, which is an electromechanical solenoid.

Pneumatic

The following is taken from Wikipedia, “Pneumatic Actuator.”

A pneumatic actuator mainly consists of a piston, a cylinder, and valves or ports. The piston is covered by a diaphragm, or seal, which keeps the air in the upper portion of the cylinder, allowing air pressure to force the diaphragm downward, moving the piston underneath, which in turn moves the valve stem, which is linked to the internal parts of the actuator. Pneumatic actuators may only have one spot for a signal input, top or bottom, depending on action required. Valves require little pressure to operate and usually double or triple the input force. The larger the size of the piston, the larger the output pressure can be. Having a larger piston can also be good if air supply is low, allowing the same forces with less input. These pressures are large enough to crush objects in the pipe. On 100 kilopascal (kPa) input, it would be possible to lift a small car easily, and this is only a basic, small pneumatic valve. However, the resulting forces required of the stem would be too great and cause the valve stem to fail.

This pressure is transferred to the valve stem, which is hooked up to either the valve plug or a butterfly valve. Larger forces are required in high pressure or high flow pipelines to allow the valve to overcome these forces, and allow it to move the valves moving parts to control the material flowing inside.

The valves input pressure is the control signal. This can come from a variety of measuring devices, and each different pressure is a different set point for a valve. A typical standard signal is 20–100 kPa. For example, a valve could be controlling the pressure in a vessel which has a constant out-flow, and a varied in-flow. A pressure transmitter will monitor the pressure in the vessel and transmit a signal from 20–100 kPa. 20 kPa means there is no pressure, 100 kPa means there is full range pressure. As the pressure rises in the vessel, the output of the transmitter rises, this increase in pressure is sent to the valve, which causes the valve to stroke downward, and start closing the valve, decreasing flow into the vessel, reducing the pressure in the vessel as excess pressure is evacuated through the out flow. This is called a direct acting process.

Hydraulic

The following is taken from Hydraulicactuator.net, “Hydraulic Actuator: Types and Design.”

A hydraulic actuator is actually a motorized appliance that uses hydraulics for converting power into linear movement. The mechanical power that is generated is normally used for lifting or pressing things, which calls for a lot of energy. Fluids have the capability of storing energy in the form of force, and they are also capable of transferring this power or energy as fluid flow, and can also convert this stacked energy into motion. This is the principle on which a hydraulic actuator works. A hydraulic actuator uses flowing fluid for transferring energy directly from the point of generation to the point of actuation. The needed fluid energy is produced in the shape of high pressure liquid by way of a pump that is driven by means of an electric motor. In most cases, heavy equipment relies on numerous actuators for proper functioning.

A hydraulic actuator comes in a number of piston types and designs and is commonly used for those applications that require loads of force for operating the valve. The movement of a hydraulic actuator is controlled by changes made in the amount of hydraulic liquid that is inside it. Earlier people used water as hydraulic liquid, but with developments in the field of chemical engineering, special oils have been designed which are used for this specific purpose. When pressure is exerted on one end of a hydraulic actuator, the fluid increases in the pressure manifold, which then converts it into mechanical movement. This is the mechanism that helps these actuators to generate great power.

A typical hydraulic actuator comes in the piston-type and it is comprised of a piston, hydraulic supply, return line, stem, spring, and a cylinder. The piston in a hydraulic actuator slides perpendicularly within the cylinder, and it divides the cylinder into two different compartments. The spring is in the top compartment and hydraulic oil fills the lower compartment. The return line and hydraulic supply are linked with the lower compartment, which enables the hydraulic fluid to flow from and to the lower compartment of the actuator.

When the hydraulic fluid enters into the lower compartment, the pressure tends to augment. The generated pressure results in a force on the base of the actuator's piston contradictory to force generated by the spring of the hydraulic actuator. This piston will start to move up, once the hydraulic force is more than the spring force. On the other side, when the oil is exhausted, the force will decrease as compared to the spring force and so the piston will move down as a result.

There are more than a few machines that benefit from the way a hydraulic actuator works. The majority of actuators act similar to the muscles of our arm, which can pull and push a machine. This provides enhanced flexibility in its movement. The principle on which a hydraulic actuator works is similar to the working of a pneumatic actuator. Both of these make use of motive force to overcome spring force to move the valve. Another feature of hydraulic actuators is that these can be designed with features like fail-closed and fail-open. This will make them safer. Apart from being safe, other features that make hydraulic machines advantageous include agility and accuracy.

f. Describe the principles of operation and the applications for modulating and pressure-reducing valves.

Modulating Valves

The following is taken from Nuclear Exchange, “A Descriptive Definition of Valve Actuators.”

If an actuator is required to control a level, flow, or pressure in a system, then it may be required to move frequently. Modulating or positioning control can be achieved using a 4-20 milliamps signal. However, the signal would change as frequently as the process required. If very high rates of modulation are required then special modulating control valve actuators are needed that can accommodate the frequent starts required for such duty.

Pressure-Reducing Valves

The following is taken from eHow, “How Does a Pressure-Reducing Valve Work?”

Pressure reducing valves reduce the pressure of inflowing water so that it comes out of the valve more slowly than it entered. They are used to reduce waste and to keep pipes from bursting when water enters a home under higher pressure from the municipality’s water source. They are made out of sturdy material, such as brass, to withstand the force that they are constantly under.

Pressure reducing valves have several parts. The inlet and outlet ends are connected to the piping where needed. Other parts include a spring, a diaphragm, and a pintle. The spring and diaphragm are on the side of the valve, and the pintle moves in the middle to open and close the valve to relieve the pressure.

The inflowing water pushes against the diaphragm inside the valve. The spring is on the other side of the diaphragm, and when the water tries to force the diaphragm in one direction, the spring forces the diaphragm back the other way. This slows the flow of water so that it doesn’t come out as quickly and, in doing so, evens out the pressure. The most common place to find pressure reducing valves is right after a water meter, which helps ensure that the flow of water into a house is even and won’t damage pipes or fixtures.

Mandatory Performance Activities:

- a. Given a drawing of a valve, identify which of the following general types of valves it is and describe its normal design application in a piping system:**
- Gate
 - Globe
 - Ball
 - Check
 - Butterfly
 - Regulating/reducing

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity. The following information may be useful.

Gate

The following is taken from Wikipedia, “Gate Valve.”

The gate valve, also known as a sluice valve, is a valve that opens by lifting a round or rectangular gate/wedge out of the path of the fluid. The distinct feature of a gate valve is the sealing surfaces between the gate and seats are planar, so gate valves are often used when a



Source: Wikipedia, Gate Valve

Figure 49. Gate valve

straight-line flow of fluid and minimum restriction is desired. The gate faces can form a wedge shape or they can be parallel. Gate valves are primarily used to permit or prevent the flow of liquids, but typical gate valves shouldn't be used for regulating flow, unless they are specifically designed for that purpose. Because of their ability to cut through liquids, gate valves are often used in the petroleum industry. For extremely thick fluids, a specialty valve often known as a knife valve is used to cut through the liquid. On opening the gate valve, the flow path is enlarged in a highly nonlinear manner with respect to percent of opening. This means that flow rate does not change evenly with stem travel. Also, a partially open gate disk tends to vibrate from

the fluid flow. Most of the flow change occurs near shutoff with a relatively high fluid velocity causing disk and seat wear and eventual leakage if used to regulate flow. Typical gate valves are

designed to be fully opened or closed. When fully open, the typical gate valve has no obstruction in the flow path, resulting in very low friction loss.

Gate valves are characterized as having either a rising or a non-rising stem. Rising stems provide a visual indication of valve position because the stem is attached to the gate so that the gate and stem rise and lower together as the valve is operated. Non-rising stem valves may have a pointer threaded onto the upper end of the stem to indicate valve position, since the gate travels up or down the stem on the threads without raising or lowering the stem. Non-rising stems are used underground or where vertical space is limited.

Bonnets provide a leak proof closure for the valve body. Gate valves may have a screw-in, union, or bolted bonnet. Screw-in bonnet is the simplest, offering a durable, pressure-tight seal. Union bonnet is suitable for applications requiring frequent inspection and cleaning. It also gives the body added strength. Bolted bonnet is used for larger valves and higher pressure applications.

Another type of bonnet construction in a gate valve is pressure seal bonnet. This construction is adopted for valves for high pressure service, typically in excess of 2250 psi. The unique feature about the pressure seal bonnet is that the body-bonnet joint seal improves as the internal pressure in the valve increases, compared to other constructions where the increase in internal pressure tends to create leaks in the body-bonnet joint.

Gate valves may have flanged ends which are drilled according to pipeline compatible flange dimensional standards. Gate valves are typically constructed from cast iron, ductile iron, cast carbon steel, gun metal, stainless steel, alloy steels, and forged steels.

Video 36. Gate valve

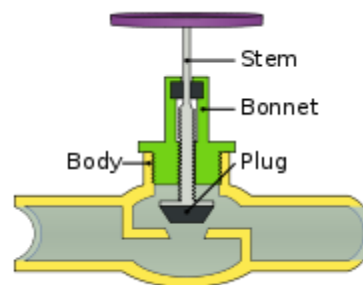
<http://vimeo.com/25405647>

Globe

The following is taken from Wikipedia, "Globe Valve."

A globe valve is a type of valve used for regulating flow in a pipeline, consisting of a movable disk-type element and a stationary ring seat in a generally spherical body.

Globe valves are named for their spherical body shape with the two halves of the body being separated by an internal baffle. This has an opening that forms a seat onto which a movable plug can be screwed in to close (or shut) the valve. The plug is also called a disc or disk. In globe valves, the plug is connected to a stem which is operated by screw action using a handwheel in manual valves. Typically, automated globe valves use smooth stems rather than threaded and are opened and closed by an actuator assembly.



Source: Wikipedia, Globe Valve

Figure 50. Globe valve

Although globe valves in the past had the spherical bodies which gave them their name, many modern globe valves do not have much of a spherical shape. However, the term globe valve is still often used for valves that have such an internal mechanism. In plumbing, valves with such a mechanism are also often called stop valves since they do not have the global appearance, but the term stop valve may refer to valves which are used to stop flow even when they have other mechanisms or designs.

Globe valves are used for applications requiring throttling and frequent operation. For example, globe valves or valves with a similar mechanism may be used as sampling valves, which are normally shut except when liquid samples are being taken. Since the baffle restricts flow, they are not recommended where full, unobstructed flow is required.

Video 37. Globe valve

<http://vimeo.com/25407536>

Ball

The following is taken from Wikipedia, “Ball Valve.”

A ball valve is a valve with a spherical disc, the part of the valve which controls the flow through it. The sphere has a hole, or port, through the middle so that when the port is in line with both ends of the valve, flow will occur. When the valve is closed, the hole is perpendicular to the ends of the valve, and flow is blocked. The handle or lever will be in line with the port position making the valve’s position visible. The ball valve, along with the butterfly valve and plug valve, are part of the family of quarter turn valves.



Source: Wikipedia, Ball Valve

Figure 51. Ball valve

Ball valves are durable and usually work to achieve perfect shutoff even after years of disuse. They are therefore an excellent choice for shutoff applications. They do not offer the fine control that may be necessary in throttling applications but are sometimes used for this purpose.

Ball valves are used extensively in industrial applications because they are very versatile, supporting pressures up to 1000 bars and temperatures up to 482°F. Sizes typically range from 0.2 to 11.81 inches. They are easy to repair and operate.

The body of ball valves may be made of metal, plastic, or metal with a ceramic center. The ball is often chrome plated to make it more durable.

Video 38. Ball valve
<http://vimeo.com/25375563>

Check

The following is taken from Wikipedia, “Check Valves.”

A check valve, clack valve, non-return valve, or one-way valve is a mechanical device, a valve, which normally allows fluid (liquid or gas) to flow through it in only one direction.

Check valves are two-port valves, meaning they have two openings in the body, one for fluid to enter and the other for fluid to leave. There are various types of check valves used in a wide variety of applications. Check valves are often part of common household items. Although they are available in a wide range of sizes and costs, check valves generally are very small, simple, and/or inexpensive. Check valves work automatically and most are not controlled by a person or any external control; accordingly, most do not have any valve handle or stem. The bodies (external shells) of most check valves are made of plastic or metal.

An important concept in check valves is the cracking pressure, which is the minimum upstream pressure at which the valve will operate. Typically the check valve is designed for and can therefore be specified for a specific cracking pressure.

Video 39. Check valve
<http://vimeo.com/25490708>

Butterfly

The following is taken from Wikipedia, “Butterfly Valve.”

A butterfly valve is a valve which can be used for isolating or regulating flow. The closing mechanism takes the form of a disk. Operation is similar to that of a ball valve, which allows for quick shut off. Butterfly valves are generally favored because they are lower in cost than other valve designs as well as being lighter in weight, meaning less support is required. The disc is positioned in the center of the pipe. Passing through the disc is a rod connected to an actuator on the outside of the valve. Rotating the actuator turns the disc either parallel or perpendicular to the flow. Unlike a ball valve, the disc is always present within the flow; therefore a pressure drop is always induced in the flow, regardless of valve position.

A butterfly valve is from a family of valves called quarter-turn valves. The butterfly is a metal disc mounted on a rod. When the valve is closed, the disc is turned so that it completely blocks off the passageway. When the valve is fully open, the disc is rotated a quarter turn so that it allows an almost unrestricted passage of the fluid. The valve may also be opened incrementally to throttle flow.

There are different kinds of butterfly valves, each adapted for different pressures and different usage. The resilient butterfly valve, which uses the flexibility of rubber, has the lowest pressure rating. The high performance butterfly valve, used in slightly higher-pressure systems, features a slight offset in the way the disc is positioned, which increases the valve’s sealing ability and decreases its tendency to wear. The valve best suited for high-pressure systems is the triple offset butterfly valve, which makes use of a metal seat and is therefore able to withstand a greater amount of pressure.

Video 40. Butterfly valve

<http://www.bing.com/videos/search?q=butterfly+valve&view=detail&mid=E7610DAC6A1D0C1DA7FFE7610DAC6A1D0C1DA7FF&first=0>

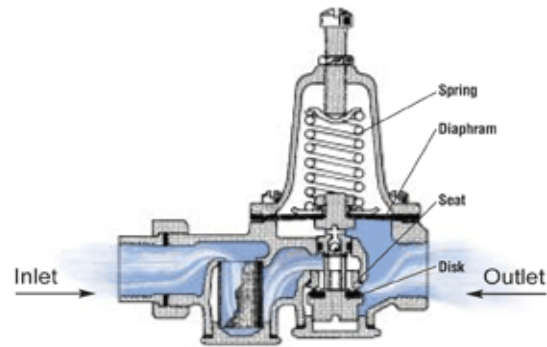
Regulation/Reducing

The following is taken from Watts Water Technologies, “Water Pressure Reducing Valves.”

There are two types of water pressure reducing valves: direct acting and pilot operated. Both use globe or angle style bodies. Valves used on smaller piping diameter units are cast from brass; larger piping diameter units are made from ductile iron. Direct acting valves, the more popular type of a water pressure reducing valves, consist of globe-type bodies with a spring-loaded, heat-resistant diaphragm connected to the outlet of the valve that acts upon a spring. This spring holds a pre-set tension on the valve seat installed with a pressure equalizing mechanism for precise water pressure control.

Water entering the valve from municipal mains is constricted within the valve body and directed through the inner chamber controlled by an adjustable spring loaded diaphragm and disc.

Even if the supply water pressure fluctuates, the pressure reducing valve ensures a constant flow of water at a functional pressure, as long as the supply pressure does not drop below the valve’s pre-set pressure.



Source: Watts Water Technologies, *Water Pressure Reducing Valves*

Figure 52. Pressure reducing valve

- b. Given a diagram of a globe valve, identify how the valve must be oriented related to flow.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

13. Mechanical systems personnel shall demonstrate a working level knowledge of safety and relief devices.

- a. Define the following terms as they pertain to safety and relief valves:

- Set point
- Accumulation
- Blowdown
- Weep
- Pilot-actuated
- Gagging device

Set Point

The following is taken from eHow, “How to Determine Relief Valve Set Points.”

The American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code* has established a requirement that all rated pressure vessels be provided with an overpressure safety device. A relief valve is a mechanical device that contains an internal spring that applies force to a metal seat or piston. This seat seals the pressure vessel from the atmosphere. If the internal pressure of the vessel increases to certain limits, the spring force in the valve is overcome and

the pressure is released. The set pressure of the valve is determined by the vessel's maximum allowable working pressure (MAWP).

To determine the set point follow these steps:

1. Determine the MAWP of the vessel. This is typically done by the vessel's manufacturer and involves detailed calculations based on vessel materials, wall thicknesses, design temperatures and vessel construction. For instance, a large cylindrical vessel could have a MAWP of 100 psi.
2. Determine the vessel's operating temperature. This is done by the process engineers designing the equipment and the system. If the operating temperature is very high, it could have an impact on the determination of the relief valve set pressure. High temperatures generally cause the set pressure to be lower than the MAWP of the vessel.
3. Determine the relief valve set point based on the equipment to be protected from overpressure. Every piece of pressure-rated equipment has a MAWP. ASME code dictates that a relief valve must be set at or below the protected equipment's MAWP. For example, depending on the operating temperature of the process, the relief valve set pressure can be at most 100 psi (the MAWP of the protected vessel). It is against code to set a relief valve higher than a vessel's MAWP. If the operating temperature is very high, the set pressure could be 95 to 98 psi.

Accumulation

The following is taken from evalvesonline.com, "Terminology."

Accumulation is the pressure increase over MAWP of the vessel during discharge through the pressure relief valve, expressed as a percentage of that pressure or actual pressure units.

Blowdown

The following is taken from evalvesonline.com, "Blowdown."

Blowdown is the difference between the set pressure and the reseating pressure of a pressure relief valve expressed as a percentage of the set pressure or actual pressure units.

Weep

The following is taken from Wikipedia, "Weep."

A weep or a weep-brick is a small opening that allows water to drain from within an assembly. Weeps are located at the bottom of the object to allow for drainage; the weep hole must be sized adequately to overcome surface tension.

In building construction, weeps are typically found in a masonry cavity wall, just above the flashing. Weeps may take several forms, including

- open head joints (the vertical joints between bricks)
- cotton rope wicking
- formed plastic or metal tubes, which may include insect screening

Weeps may also be necessary in a retaining wall, so water can escape from the retained earth, thus lessening the hydrostatic load on the wall and preventing moisture damage from freeze/thaw cycles. In such cases the weeps consist of small-diameter plastic, clay or metal pipes extending through the wall to a layer of porous backfill.

Typically, weeps are arranged to direct water which may have entered an assembly from outside back to the outside. Weeps may also be found in metal windows and glazed curtain walls to permit internal condensation to escape.

Pilot Actuated

The following is taken from Integrated Publishing, “Internal Pilot-Actuated Pressure-Reducing Valve.”

The internal pilot-actuated pressure-reducing valve, shown in figure 53, uses a pilot valve to control the flow of upstream fluid, which is ported to the pilot valve, to the operating piston, which operates the main valve. The main valve is opened by the operating piston and closed by the main valve spring. The pilot valve opens when the adjusting spring pushes downward on the pilot diaphragm. It closes when downstream pressure exerts a force that exceeds the force of the adjusting spring. When the pilot valve shuts off or throttles the flow of upstream fluid to the operating piston, the main valve pushes the valve and stem upward to throttle or closes the main valve. When downstream pressure falls below the set point, the adjusting spring force acts downward on the diaphragm. This action overcomes the force of the downstream system pressure, which is acting upward on the diaphragm. This opens the pilot valve, allowing upstream pressure to the top of the operating piston to open the main valve.

Gagging Device

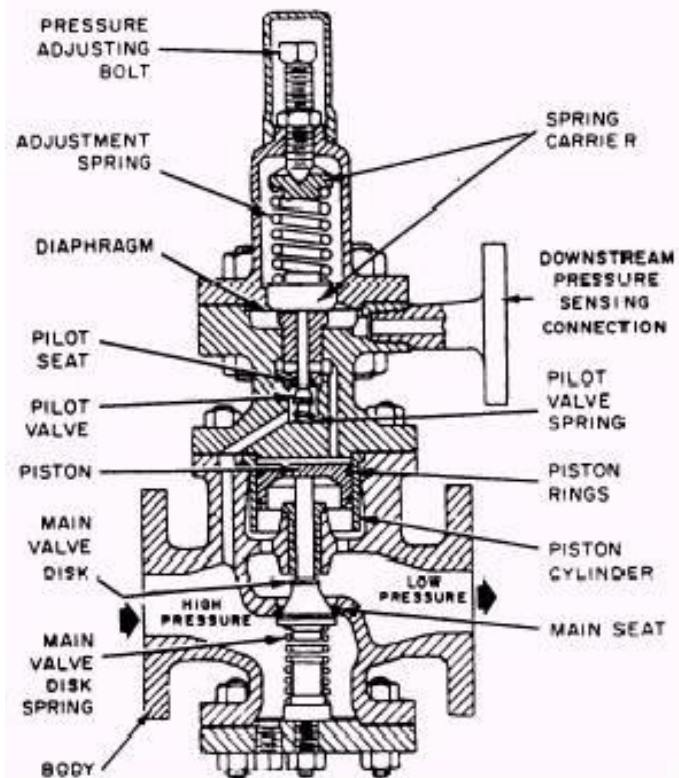
According to DOE-STD-1030-96, a gagging device is a device designed to block off or obstruct operation of a valve.

b. Compare and contrast the purpose and operation of safety and relief valves.

The following is taken from Wikipedia, “Safety Valve.”

A relief valve is an automatic system that is actuated by the static pressure in a liquid-filled vessel. It specifically opens proportionally with increasing pressure.

A safety valve is an automatic system that relieves the static pressure on a gas. It usually opens completely, accompanied by a popping sound.



Source: Integrated Publishing, *Internal Pilot-Actuated Pressure-Reducing Valve*

Figure 53. Pilot-actuated valve

c. Discuss how blowdown and accumulation are controlled in safety and relief valves.

According to DOE-HDBK-1018/2-93, blowdown and accumulation can be set by the manufacturer or with adjustment screws on the valve. Different valves have different types of adjustment requirements that are performed according to manufacturer recommendations.

d. Discuss the methods used to test relief valves.

The following is taken from the *Companion Guide to the ASME Boiler & Pressure Vessel Code* by K.R. Rao.

Pressure-relief valves should be tested after being repaired to ensure that the valves will function properly. There are various methods used for testing. Some organizations use a simple hydraulic hand pump for all testing for steam, air, gas, or water service. Other organizations use a nitrogen gas source connected directly to the underside of the valve to be tested. These are not appropriate methods because testing should be performed with the same or similar test media, and suitable capacity should be provided to test the functions of the valve.

A more informed organization may add sophistication to its testing program by constructing a J-watertube test-stand device for liquid service valves or a nitrogen gas test-stand device for steam, air, and gas service valves. These devices are an improvement from the other testing methods described, for the capacity for testing has increased, similar testing media are used, and the strength or thickness of each design determines the maximum set pressure test. However, for the nitrogen gas test-stand device, the capacity is often insufficient because of the sizes usually built, the source capacity, and the hazards involved when testing is done with a compressible fluid. If steam service valves are tested, it is recommended that the test stand have heating provisions to replicate the in-service temperature of the valve.

More sophisticated organizations build or procure larger test systems with larger volume test vessels and accumulator vessels, digital pressure gages, larger pressure sources, and that use the proper test medium. They verify the quality of workmanship for all functions, including lift and blowdown, depending on the capacity of the test system and the size of valve tested.

e. Discuss the application of rupture discs.

The following is taken from Wikipedia, “Rupture Disc.”

A rupture disc, also known as a bursting disc or burst diaphragm, is a non-reclosing pressure relief device that, in most uses, protects a pressure vessel, equipment, or system from overpressurization or potentially damaging vacuum conditions. A rupture disc is a type of sacrificial part because it has a one-time-use membrane that fails at a predetermined differential pressure, either positive or vacuum. The membrane is usually made out of metal, but nearly any material can be used to suit a particular application. Rupture discs provide instant response to an increase or decrease in system pressure, but once the disc has ruptured it will not reseal. Major advantages of the application of rupture discs compared to using pressure relief valves include leak-tightness and cost.

Rupture discs are commonly used in petrochemical, aerospace, aviation, defense, medical, railroad, nuclear, chemical, pharmaceutical, food processing, and oilfield applications. They can be used as single protection devices or as backup devices for conventional safety valves; if the pressure increases and the safety valve fails to operate, the rupture disc will burst. Rupture discs

are very often used in combination with safety relief valves, isolating the valves from the process, thereby saving on valve maintenance and creating a leak-tight pressure relief solution.

Mandatory Performance Activities:

- a. **Given a cutaway drawing of a safety valve, identify the main components, including the following:**
- **Seat**
 - **Disc**
 - **Blowdown ring**
 - **Main ring**
 - **Set-point adjustment mechanism**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of this activity.

14. Mechanical systems personnel shall demonstrate a working level knowledge of pump theory and operation.

- a. **Define the following terms as they relate to pumps:**
- **Head**
 - **Net positive suction head**
 - **Cavitation**
 - **Shut-off head**
 - **Run-out**
 - **Centrifugal pump**
 - **Positive displacement pump**

Head/Shut-Off Head

The following is taken from The Engineering ToolBox, “An Introduction to Centrifugal Pumps.”

If the discharge of a centrifugal pump is pointed straight up into the air the fluid will be pumped to a certain height or head called the shut-off head. This maximum head is mainly determined by the outside diameter of the pump’s impeller and the speed of the rotating shaft. The head will change as the capacity of the pump is altered.

The kinetic energy of a liquid coming out of an impeller is obstructed by creating a resistance in the flow. The first resistance is created by the pump casing that catches the liquid and slows it down. When the liquid slows down the kinetic energy is converted to pressure energy.

It is the resistance to the pump’s flow that is read on a pressure gauge attached to the discharge line.

A pump does not create pressure, it only creates flow. Pressure is a measurement of the resistance to flow.

In Newtonian fluids (non-viscous liquids like water or gasoline) the term head is used to measure the kinetic energy that a pump creates. Head is a measurement of the height of the liquid column the pump creates from the kinetic energy the pump gives to the liquid.

The main reason for using head instead of pressure to measure a centrifugal pump’s energy is that the pressure from a pump will change if the specific gravity (weight) of the liquid changes, but the head will not.

The pump's performance on any Newtonian fluid can always be described by using the term head.

Different Types of Pump Head

- Total Static Head—Total head when the pump is not running
- Total Dynamic Head (Total System Head)—Total head when the pump is running
- Static Suction Head—Head on the suction side, with pump off, if the head is higher than the pump impeller
- Static Suction Lift—Head on the suction side, with pump off, if the head is lower than the pump impeller
- Static Discharge Head—Head on discharge side of pump with the pump off
- Dynamic Suction Head/Lift—Head on suction side of pump with pump on
- Dynamic Discharge Head—Head on discharge side of pump with pump on

The head is measured in either feet or meters and can be converted to common units for pressure as psi or bar.

The only difference between the fluids is the amount of power it takes to get the shaft to the proper rpm. The higher the specific gravity of the fluid, the more power is required.

The head of a pump in metric units can be expressed in metric units as:

$$h = (p_2 - p_1)/(\rho g) + v_2^2/(2g)$$

where

h = total head developed (m)

p_2 = pressure at outlet (N/m^2)

p_1 = pressure at inlet (N/m^2)

ρ = density (kg/m^3)

g = acceleration of gravity (9.81) m/s^2

v_2 = velocity at the outlet (m/s)

A pump's vertical discharge "pressure-head" is the vertical lift in height, usually measured in feet or meters of water, at which a pump can no longer exert enough pressure to move water. At this point, the pump may be said to have reached its shut-off head pressure. In the flow curve chart for a pump the shut-off head is the point on the graph where the flow rate is zero.

Net Positive Suction Head

The following is taken from The Engineering ToolBox, "Net Positive Suction Head."

The net positive suction head (NPSH) can be expressed as the difference between the suction head and the liquid's vapor head and expressed as

$$\text{NPSH} = h_s - h_v$$

or, by

$$\text{NPSH} = p_s / \gamma + v_s^2 / 2g - p_v / \gamma$$

The NPSH made available in the suction system for the pump is often named NPSH_a . The NPSH_a can be determined during design and construction, or determined experimentally from the actual physical system.

The available $NPSH_a$ can be calculated with the energy equation. For a common application where the pump lifts a fluid from an open tank at one level to another, the energy or head at the surface of the tank is the same as the energy or head before the pump impeller and can be expressed as:

$$h_o = h_s + h_i$$

where

h_o = head at surface

h_s = head before the impeller

h_i = head loss from the surface to impeller—major and minor loss in the suction pipe

In an open tank the head at surface can be expressed as:

$$h_o = p_o/\gamma = p_{atm}/\gamma$$

For a closed pressurized tank, the absolute static pressure inside the tank must be used. The head before the impeller can be expressed as:

$$h_s = p_s/\gamma + v_s^2/2g + h_e$$

where

h_e = elevation from surface to pump—positive if pump is above the tank, negative if the pump is below the tank.

The $NPSH_r$ is required by the pump to prevent cavitation for safe and reliable operation of the pump.

The required $NPSH_r$ for a particular pump is determined experimentally by the pump manufacturer and is a part of the documentation of the pump.

The available $NPSH_a$ of the system should always exceed the required $NPSH_r$ of the pump to avoid vaporization and cavitation of the impellers eye. The available $NPSH_a$ should be significantly higher than the required $NPSH_r$ to avoid head loss in the suction pipe and in the pump casing, local velocity accelerations, and pressure decreases that can start boiling the fluid on the impeller surface.

Note that the required $NPSH_r$ increases with the square capacity.

Pumps with double-suction impellers have lower $NPSH_r$ than pumps with single-suction impellers. A pump with a double-suction impeller is considered hydraulically balanced but is susceptible to uneven flow on both sides with improper pipe-work.

Video 41. Net Positive Suction Head

<http://www.bing.com/videos/search?q=net+positive+suction+head&view=detail&mid=67BD9165C855AF0E029E67BD9165C855AF0E029E&first=0>

Cavitation

The following is taken from WiseGeek, “What is Cavitation?”

When the liquid being pumped enters the eye of a centrifugal pump, the pressure is significantly reduced. The greater the flow velocity through the pump, the greater this pressure drop. If the pressure drop is great enough, or if the temperature of the liquid is high enough, the pressure drop may be sufficient to cause the liquid to flash to steam when the local pressure falls below

the saturation pressure for the fluid that is being pumped. The vapor bubbles created are swept along the pump impeller with the fluid. As the flow velocity decreases, the fluid pressure increases. This causes the vapor bubbles to suddenly collapse on the outer portions of the impeller. The formation of these vapor bubbles and their subsequent collapse is cavitation.

Runout

The following is taken from Electric Power Research Institute, *Engineering Training Module 4 - Centrifugal Pumps*.

Pump runout refers to the maximum flow rate at the lowest anticipated system head. Pumps that operate in an oversized system can reach their maximum flow rates due to too low a system head loss. Correctly sized pumps can reach runout due to ruptures in the system that drastically reduce head loss.

Runout results in

- pump efficiency decreasing—the runout flow is typically much higher than the best efficiency point
- eventual flow loss (possible cavitation problems)—the runout flow typically has much higher NPSH requirements

Centrifugal Pump

The following is taken from The Engineering ToolBox, “An Introduction to Centrifugal Pumps.”

A centrifugal pump converts the input power to kinetic energy in the liquid by accelerating the liquid by a revolving device - an impeller. The most common type is the volute pump. Fluid enters the pump through the eye of the impeller which rotates at high speed. The fluid is accelerated radially outward from the pump casing. A vacuum is created at the impeller's eye that continuously draws more fluid into the pump.

The energy created by the pump is kinetic energy according to the Bernoulli equation. The energy transferred to the liquid corresponds to the velocity at the edge or vane tip of the impeller. The faster the impeller revolves or the bigger the impeller is, the higher the velocity of the energy transferred to the liquid will be.

Video 42. Centrifugal pump

<http://www.youtube.com/watch?v=9nL1XhKm9q8>

Positive Displacement Pump

The following is taken from The Engineering ToolBox, “Positive Displacement Pumps.”

PD pumps have an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pumps as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant given each cycle of operation.

PD pumps can be divided into two main classes

1. reciprocating
2. rotary

PD pumps, unlike centrifugal or rotodynamic pumps, will produce the same flow at a given speed no matter the discharge pressure.

A PD pump must not be operated against a closed valve on the discharge side of the pump because it has no shut-off head like centrifugal pumps. A PD pump operating against a closed discharge valve will continue to produce flow until the pressure in the discharge line is increased to the point that the line bursts or the pump is severely damaged or both.

b. Describe the general principle of operation for centrifugal pumps.

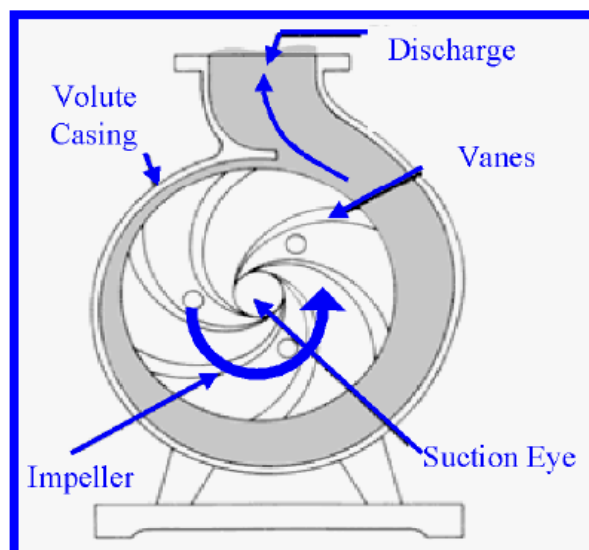
The following is taken from the Chemical Engineer's Resource, "Centrifugal Pumps: Basic Concepts of Operation, Maintenance, and Troubleshooting."

A centrifugal pump is one of the simplest pieces of equipment in any process plant. Its purpose is to convert energy of a prime mover first into velocity or kinetic energy and then into pressure energy of a fluid that is being pumped. The energy changes occur by virtue of two main parts of the pump, the impeller and the volute or diffuser. The impeller is the rotating part that converts driver energy into the kinetic energy. The volute or diffuser is the stationary part that converts the kinetic energy into pressure energy.

The process liquid enters the suction nozzle and then goes into the eye (center) of a revolving device known as an impeller. When the impeller rotates, it spins the liquid sitting in the cavities between the vanes outward and provides centrifugal acceleration.

As liquid leaves the eye of the impeller, a low-pressure area is created, causing more liquid to flow toward the inlet. Because the impeller blades are curved, the fluid is pushed in a tangential and radial direction by the centrifugal force. This force acting inside the pump is the same one that keeps water inside a bucket that is rotating at the end of a string. Figure 54 depicts a side cross-section of a centrifugal pump indicating the movement of the liquid.

The key idea is that the energy created by the centrifugal force is kinetic energy. The amount of energy given to the liquid is proportional to the velocity at the edge or vane tip of the impeller. The faster the impeller revolves or the bigger the impeller is, then the higher will be the velocity of the liquid at the vane tip and the greater the energy imparted to the liquid.



Source: Chemical Engineer's Resource, Centrifugal Pumps: Basic Concepts of Operation, Maintenance, and Troubleshooting

Figure 54. Centrifugal pump

This kinetic energy of a liquid coming out of an impeller is harnessed by creating a resistance to the flow. The first resistance is created by the pump volute (casing) that catches the liquid and slows it down. In the discharge nozzle, the liquid further decelerates and its velocity is converted to pressure according to Bernoulli's principle. Therefore, the head developed is approximately equal to the velocity energy at the periphery of the impeller expressed by the following well-known formula:

$$H = \frac{v^2}{2g}$$

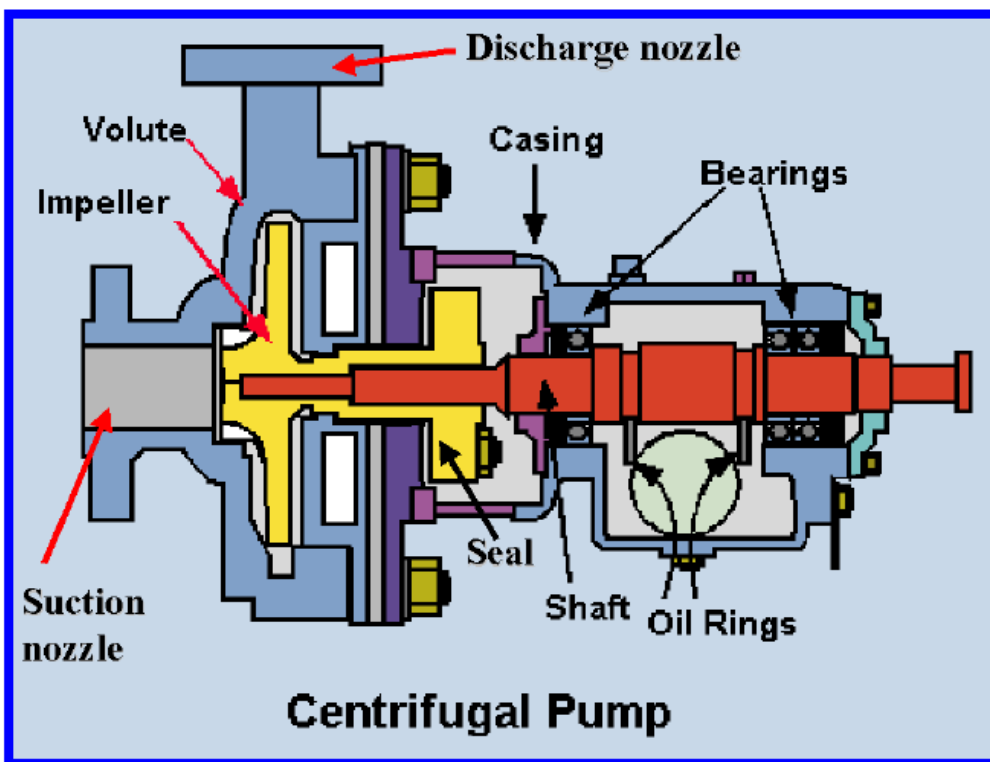
where

- **H = Total head developed in feet.**
- **v = Velocity at periphery of impeller in ft/sec.**
- **g = Acceleration due to gravity - 32.2 feet/Sec²**

A centrifugal pump has two main components:

1. A rotating component comprised of an impeller and a shaft
2. A stationary component comprised of a casing, casing cover, and bearings

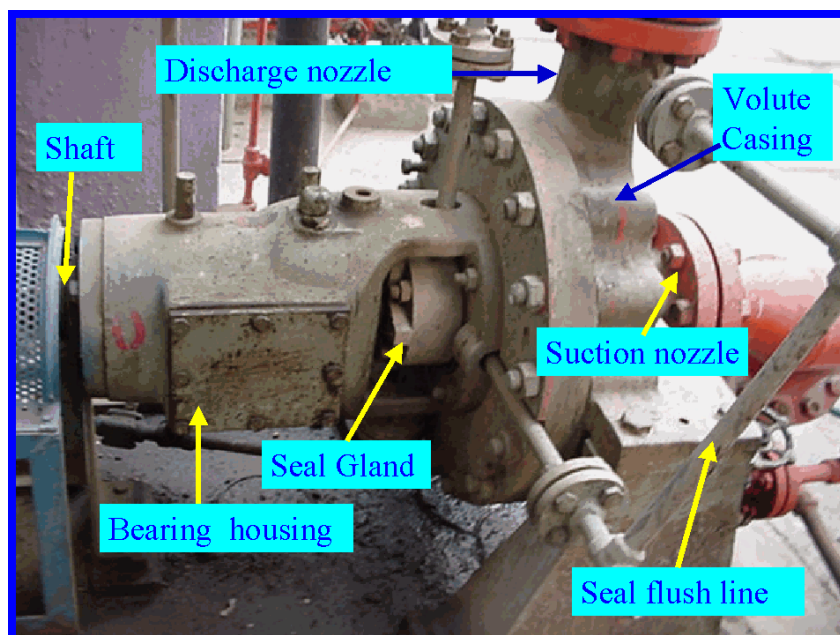
The general components, both stationary and rotary, are depicted in figure 55.



Source: *Chemical Engineer's Resource, Centrifugal Pumps: Basic Concepts of Operation, Maintenance, and Troubleshooting*

Figure 55. Centrifugal pump components

Figure 56 shows these parts on a photograph of a pump in the field.



Source: *Chemical Engineer's Resource, Centrifugal Pumps: Basic Concepts of Operation, Maintenance, and Troubleshooting*

Figure 56. General components of a centrifugal pump

c. Describe the general principle of operation for positive displacement pumps.

The following is taken from Pump World, "Positive Displacement Pumps."

A PD pump has an expanding cavity on the suction side of the pump and a decreasing cavity on the discharge side. Liquid is allowed to flow into the pump as the cavity on the suction side expands and the liquid is forced out of the discharge as the cavity collapses. This principle applies to all types of PD pumps whether the pump is a rotary lobe, gear within a gear, piston, diaphragm, screw, progressing cavity, etc.

A PD pump, unlike a centrifugal pump, will produce the same flow at a given rpm no matter what the discharge pressure is. A PD pump cannot be operated against a closed valve on the discharge side of the pump, i.e. it does not have a shut-off head like a centrifugal pump does. If a PD pump is allowed to operate against a closed discharge valve it will continue to produce flow which will increase the pressure in the discharge line until either the line bursts or the pump is severely damaged or both.

d. Discuss Bernoulli's law as it applies to the design and operation of centrifugal pumps.

The following is taken from Pump Consulting and Training, "How Centrifugal Pumps Pump and Airplanes Fly."

For the study of pumps and pumping systems, the energy within a pump or pumping system is referred to as its head energy. Head energy is that energy contained in that fluid per pound or

unit mass. In general, a liquid may have three kinds of head energy, or stated another way; the capacity to do work may be due to three forms of energy:

1. Potential Head Energy is defined as that work that can be done or is possible from a liquid falling from a vertical distance. The head energy component is designated as 'Z', which is usually determined by a height distance above or below the system in question.
2. Static Pressure Head Energy is defined as an equivalent height to which a liquid can be raised by a given pressure. To stay in context with the concept of head, pressure head energy units are normally converted to equivalent heights to which a liquid could be raised by that pressure. The pressure head energy component is designated as 'P' = $[\text{PSI} \times 2.31] / \text{s.g.}$ where PSI is the pounds per square inch of pressure and s.g. is the fluid's specific gravity.
3. Velocity Head Energy is defined as the vertical distance a liquid would have to fall to acquire the velocity "V". By definition velocity head = $V^2/2g$. This definition comes from the Law of a Falling Body, which states that when the height of a body falling to earth is known, it is possible to theoretically predict what its terminal velocity (neglecting air resistance for this discussion) will be upon hitting the earth. Conversely, knowing the velocity of a body as it exits upward it is possible to theoretically determine to what height or head it will travel or how much work the fluid can do.

$$H = V^2/2g$$

Where

H = Height of falling body, or head in feet, to attain 'V' equivalent to the velocity head

V = Velocity of moving or falling body from height 'H', in feet per second

g = Acceleration due to gravity ($\sim 32.2 \text{ feet/second}^2$)

Further elaboration on how velocity is determined will help to understand how all this comes together.

By definition: flow is defined as

$$Q = V \times A.$$

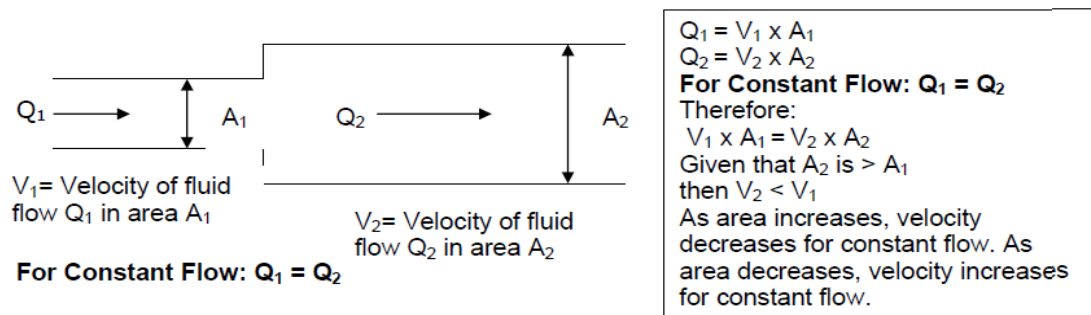
Where

Q = Flow value of our fluid flowing through cross sectional A @ Velocity V

V = Velocity of fluid through the cross sectional area A

A = Cross Sectional Area through which the fluid flows

From the definition in figure 57, if the fluid flow Q is constant, and the cross sectional area from area 1 (A_1) to area 2 (A_2) through which the fluid flows is increased, then the fluid velocity V must decrease, as will the fluid velocity head energy $V^2/2g$. Conversely, if the cross sectional area through which the fluid flows is reduced, then the fluid velocity V must increase, as will the fluid velocity head energy $V^2/2g$.



Source: Pump Consulting and Training, How Centrifugal Pumps Pump and Airplanes Fly

Figure 57. Example of velocity

The total sum of all the energies at any given point in a pumping system is comprised of three types of energy.

Total Head Energy = Potential Head Energy (Z) + Static Pressure Head Energy (P) + Velocity Head Energy ($V^2/2g$).

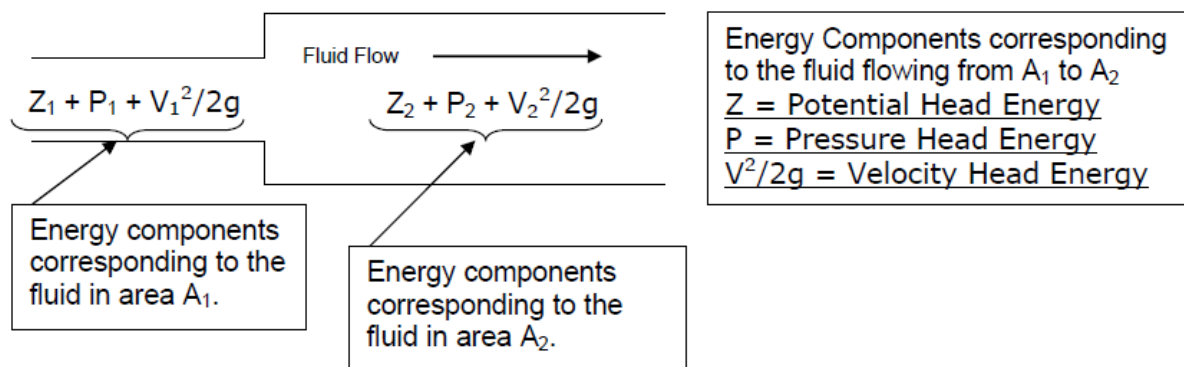
This can be stated as: Head = $Z + P + V^2/2g$. At any given point in the pumping system there will be these three energy forms.

Since the Law of Conservation of Energy states that energy cannot be created or destroyed but only converted from one form to another, figure 57 can be expanded to include 3 energy forms to further the discussion. In keeping with the laws of thermodynamics and conservation of energy, Bernoulli's Principle states that the sum of all forms of energy in a fluid flowing along a streamline is the same at any two points in that path.

Therefore

$$Z_1 + P_1 + V_1^2/2g = Z_2 + P_2 + V_2^2/2g$$

as shown in figure 58.



Source: Pump Consulting and Training, How Centrifugal Pumps Pump and Airplanes Fly

Figure 58. Bernoulli's Principle states that the sum of all forms of energy in a fluid flowing along a streamline is the same at any two points in that path.

For all practical purposes, the fluids potential energy component (Z) is the same for area A₁ as it is for area A₂. There is little to no difference in the vertical distance of the fluid flowing in the

example. Therefore it is correct to say that $Z_1=Z_2$. From this conclusion Bernoulli's equation can be simplified to read:

$$P_1 + V_1^2/2g = P_2 + V_2^2/2g$$

From this it can be seen that for the fluid flowing from area A_1 to area A_2 , the conservation of energy will be limited to energy changes in the pressure head energy and velocity head energy only. From figure 57 it was determined that the fluid velocity changed inversely as the area changed and thus the velocity head energy component also changed accordingly. From this it can be seen that area 2 increased from area 1, with a corresponding decrease in velocity and velocity head energy. Therefore, to comply with Bernoulli's principle and the Law of Conservation of Energy, if the velocity head energy decreases, then the pressure head energy (P) must increase.

In keeping with the laws of thermodynamics and conservation of energy, Bernoulli's principle states that in an ideal fluid a decrease in velocity will simultaneously result in an increase in pressure, and that an increase in velocity will simultaneously yield a decrease in pressure. This is known today as the Bernoulli effect.

e. Discuss why centrifugal pumps should normally be started against a shut-off head and the hazards associated with continuously running against a shut-off head.

The following is taken from DOE-HDBK-1018/1-93.

A centrifugal pump is dead-headed when it is operated with no flow through it, for example, with a closed discharge valve or against a seated check valve. If the discharge valve is closed and there is no other flow path available to the pump, the impeller will churn the same volume of water as it rotates in the pump casing. This will increase the temperature of the liquid (due to friction) in the pump casing to the point that it will flash to vapor. The vapor can interrupt the cooling flow to the pump's packing and bearings, causing excessive wear and heat. If the pump is run in this condition for a significant amount of time, it will become damaged.

When a centrifugal pump is installed in a system such that the pump may be subjected to periodic shutoff head conditions, it is necessary to provide some means of pump protection. One method for protecting the pump from running dead-headed is to provide a recirculation line from the pump discharge line upstream of the discharge valve, back to the pump's supply source. The recirculation line should be sized to allow enough flow through the pump to prevent overheating and damage to the pump. Protection may also be accomplished by use of an automatic flow control device.

f. Compare and contrast the principle of operation and typical pumped medium of the following types of positive displacement pumps:

- Reciprocating
- Rotary-screw
- Vane-axial

Reciprocating

The following is taken from Wikipedia, “Pump.”

Reciprocating pumps are those which cause the fluid to move using one or more oscillating pistons, plungers or membranes, and restrict motion of the fluid to the one desired direction by valves.

Pumps in this category range from simplex, with one cylinder, to in some cases quad (four) cylinders or more. Many reciprocating-type pumps are duplex (two) or triplex (three) cylinder. They can be either single-acting with suction during one direction of piston motion and discharge on the other, or double-acting with suction and discharge in both directions. The pumps can be powered manually, by air or steam, or by a belt driven by an engine. This type of pump was used extensively in the early days of steam propulsion for boiler feed water pumps. Reciprocating pumps are now typically used for pumping highly viscous fluids including concrete and heavy oils, and special applications demanding low flow rates against high resistance. Reciprocating hand pumps were widely used for pumping water from wells; the common bicycle pump and foot pumps for inflation use reciprocating action.

These PD pumps have an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pumps as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant given each cycle of operation.

Typical reciprocating pumps include the following:

- Plunger pumps—a reciprocating plunger pushes the fluid through one or two open valves, closed by suction on the way back.
- Diaphragm pumps—similar to plunger pumps, where the plunger pressurizes hydraulic oil that is used to flex a diaphragm in the pumping cylinder. Diaphragm valves are used to pump hazardous and toxic fluids.
- Piston displacement pumps—usually simple devices for pumping small amounts of liquid or gel manually. An example is the common hand soap pump.
- Radial piston pump—a form of hydraulic pump. The working pistons extend in a radial direction symmetrically around the drive shaft, in contrast to the axial piston pump.

Video 43. Reciprocating pump

<http://www.bing.com/videos/search?q=reciprocating+pump&view=detail&mid=F11301E238E3FDFEEEBF11301E238E3FDFEEEBF&first=0>

Rotary-Screw

The following is taken from Wikipedia, “Pump.”

PD rotary pumps move fluid using a rotating mechanism that creates a vacuum that captures and draws in the liquid.

Advantages: Rotary pumps are very efficient because they naturally remove air from the lines, eliminating the need to bleed the air from the lines manually.

Drawbacks: Because of the nature of the pump, the clearance between the rotating pump and the outer edge must be very close, requiring that it rotates at a slow, steady speed. If rotary pumps are operated at high speeds, the fluids will cause erosion, eventually developing enlarged clearances through which liquid can pass, reducing the efficiency of the pump.

Rotary PD pumps can be grouped into three main types:

1. Gear pump—a simple type of rotary pump where the liquid is pushed between two gears.
2. Screw pump—a pump that uses two screws turning against each other to pump the liquid.
3. Rotary vane pump—a pump that consists of a cylindrical rotor encased in a similarly shaped housing. As the rotor orbits, the vanes trap fluid between the rotor and the casing, drawing the fluid through the pump.

Vane-Axial

The following is taken from Wikipedia, “Rotary Vane Pump.”

A rotary vane pump is a positive-displacement pump that consists of vanes mounted to a rotor that rotates inside of a cavity. In some cases these vanes can be variable length and/or tensioned to maintain contact with the walls as the pump rotates.

The simplest vane pump is a circular rotor rotating inside of a larger circular cavity. The centers of these two circles are offset, causing eccentricity. Vanes are allowed to slide into and out of the rotor and seal on all edges, creating vane chambers that do the pumping work. On the intake side of the pump, the vane chambers are increasing in volume. These increasing volume vane chambers are filled with fluid forced in by the inlet pressure. Inlet pressure is actually the pressure from the system being pumped, often just the atmosphere. On the discharge side of the pump, the vane chambers are decreasing in volume, forcing fluid out of the pump. The action of the vane drives out the same volume of fluid with each rotation. Multistage rotary vane vacuum pumps can attain pressures as low as 10^{-3} megabar.

Video 44. Vane pump

http://wn.com/vane_pump#/videos

g. State the dangers to personnel and equipment associated with starting a positive displacement pump against a shut-off head.

The following is from the U.S. DOE, Energy Efficiency and Renewable Energy, “Federal Energy Management Program, Operations and Maintenance, Types of Pumps.”

A PD pump, unlike a centrifugal pump, will produce the same flow at a given rpm no matter what the discharge pressure is. A PD pump cannot be operated against a closed valve on the discharge side of the pump, i.e., it does not have a shut-off head like a centrifugal pump does. If a PD pump is allowed to operate against a closed discharge valve, it will continue to produce flow which will increase the pressure in the discharge line until either the line bursts or the pump is severely damaged or both.

h. Discuss the importance and methods of providing over-pressurization protection for positive displacement pumps.

The following is taken from DOE-HDBK-1018/1-93.

PD pumps are normally fitted with relief valves on the upstream side of their discharge valves to protect the pump and its discharge piping from over-pressurization. PD pumps will discharge at the pressure required by the system they are supplying. The relief valve prevents system and

pump damage if the pump discharge valve is shut during pump operation or if any other occurrence, such as a clogged strainer, blocks system flow.

i. Discuss the concept of pump cavitation and describe its harmful effects.

The following is taken from WiseGeek, “What is Cavitation?”

When the liquid being pumped enters the eye of a centrifugal pump, the pressure is significantly reduced. The greater the flow velocity through the pump, the greater this pressure drop. If the pressure drop is great enough, or if the temperature of the liquid is high enough, the pressure drop may be sufficient to cause the liquid to flash to steam when the local pressure falls below the saturation pressure for the fluid that is being pumped. The vapor bubbles created are swept along the pump impeller with the fluid. As the flow velocity decreases, the fluid pressure increases. This causes the vapor bubbles to suddenly collapse on the outer portions of the impeller. The formation of these vapor bubbles and their subsequent collapse is cavitation.

The following is taken from Wikipedia, “Cavitation.”

Since the shock waves formed by cavitation are strong enough to significantly damage moving parts, cavitation is usually an undesirable phenomenon. It is specifically avoided in the design of machines such as turbines or propellers, and eliminating cavitation is a major field in the study of fluid dynamics.

Cavitation is, in most cases, an undesirable occurrence. In devices such as propellers and pumps, cavitation causes noise, damage to components, vibrations, and loss of efficiency.

When the cavitation bubbles collapse, they force energetic liquid into very small volumes, thereby creating spots of high temperature and emitting shock waves, the latter of which are a source of noise. The noise created by cavitation is a particular problem for military submarines, as it increases the chances of being detected by passive sonar.

Although the collapse of a cavity is a relatively low-energy event, highly localized collapses can erode metal, such as steel, over time. The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller or pump’s lifetime.

After a surface is initially affected by cavitation, it tends to erode at an accelerated pace. The cavitation pits increase the turbulence of the fluid flow and create crevasses that act as nucleation sites for additional cavitation bubbles. The pits also increase the components’ surface area and leave behind residual stresses. This makes the surface more prone to stress corrosion.

Mandatory Performance Activities:

- a. Given a cutaway drawing of a centrifugal pump, identify the following components and discuss their purpose:**
- **Impeller**
 - **Packing or mechanical seal**
 - **Volute**
 - **Lantern ring**
 - **Wearing rings (impeller and/or casing)**

b. For each of the following system and/or pumped medium characteristics, identify the type of pump (e.g., centrifugal, reciprocating positive displacement, rotary-screw positive displacement) that is best suited for the application:

- **Slurries**
- **Fluids with high viscosities**
- **Low volume, high head**
- **Low head, high volume**
- **Water**
- **Oil**

These are performance-based KSAs. The Qualifying Official will evaluate their completion.

15. Mechanical systems personnel shall demonstrate a working level knowledge of strainers and filters.

a. Compare and contrast the design, operating characteristics, and applications of filters and strainers.

The following is taken from DOE-HDBK-1018/2-93.

Filtration is a process used to remove suspended solids from a solution. Other processes such as demineralization remove ions or dissolved ions. Different filters and strainers are used for different applications. In general, the filter passage must be small enough to catch the suspended solids but large enough that the system can operate at normal system pressures and flows. Filters and strainers are used throughout most DOE facilities. They are used in hydraulic systems, oil systems, cooling systems, liquid waste disposal, water purification, and reactor coolant systems.

Strainers are fitted in many piping lines to prevent the passage of grit, scale, dirt, and other foreign matter, which could obstruct pump suction valves, throttle valves, or other machinery parts.

b. Describe the following types of strainers and filters, including an example of typical use for each:

- **Electrostatic filters**
- **Cartridge filters**
- **Precoated filters**
- **Bucket strainers**
- **Deep-bed filters**
- **High Efficiency Particulate Air (HEPA) filters**
- **Duplex strainers**

Electrostatic Filters

The following is taken from Furnace Filter Care, “What are Electrostatic Furnace Filters and Why You Should Use One in Your Heating and Air Conditioning Equipment?”

As air passes through electrostatic filters, a static charge is created within the filter. As a result of this static charge, dust particles are attracted to the filter and remain trapped there until the filter is washed.

The air contains many allergens and irritants such as dust, bacteria, mold spores, pet dander, pollen, and smoke. Most of these particles are smaller than one micron in size and will pass

through the traditional furnace filter. When an electrostatic furnace filter is installed, the number of particles passing through a heating or cooling system and returning to a living space will be dramatically reduced.

An electrostatic air filter will save hundreds of dollars by eliminating the monthly cost of purchasing disposable filters. Typical disposable fiberglass filters are only 5-10 percent efficient. The best electrostatic air filters are over 90 percent efficient.

Cartridge Filters

The following is taken from WiseGeek, "What is a Cartridge Filter?"

A cartridge filter is a filter that uses a barrier/sift method to clean sediments and harmful solids out of water. Some of these filters are made to stop microscopic items and others are made to stop major solids from entering a system. The cartridge filter is usually a cylindrical object, though in some cases it can be flat, much like an air filter. The shape of the cartridge filter is most dependent on its location. If located in a pipe or filter housing, it will be cylindrical.

Precoated Filters

The following is taken from Kickoff, "Filters and Strainers."

A precoated filter eliminates the problem of physically handling radioactive materials, because the filter material (called the medium) can be installed and removed remotely. Inside the filter housing is a bundle of septums (vertical tubes, on which the filter medium is deposited). The septums in some filters are approximately 1 inch in diameter and 3 feet long and are usually made of perforated or porous metal (normally stainless steel). There may be several hundred of these septums in a filter. Septums in other filters are approximately 3 inches in diameter and 3 feet long and are made of porous stone or porous ceramic material. There are usually less than 100 of these larger septums in a filter. The filtering medium fibers may be finely divided diatomite, perlite, asbestos, or cellulose. Diatomite, the least expensive medium, is used to filter liquid waste that will be discharged from a plant. Cellulose is generally used for processing water that will be returned to a reactor, because diatomite can allow silica leaching. When a precoat filter is in use, water that enters the filter vessel passes through the filter medium that is deposited on the septums and then leaves through the outlet. Before the filter can be placed into operation, however, the filter medium must be installed; that is, the filter must be precoated. The first step in precoating the filter is to close the inlet and outlet valves to the filter. The filter medium used is mixed with demineralized water in an external mixing tank to form a slurry, which is pumped through the filter. Some of the filter medium deposits on the septums and is held there by the pressure of water on the outside of the septums. At the beginning of the precoating process, some of the fibers of the filter medium pass through the septums, either because they are smaller than the openings or because they pass through lengthwise. Thus, there is still some filter medium in the water as it leaves the filter, so the slurry is recirculated again and again until the water is clear. Clear water indicates that all of the filter medium is deposited on the septums, and the filter is precoated.

One characteristic of the precoating process is that a very even layer of filter medium is deposited on the septums. This occurs because the circulating slurry follows the path of least resistance. When the coating at one point reaches a certain thickness, the slurry takes the fibers to another point, and this process continues until precoating is complete. Because water pressure holds the filter in place, flow must be maintained through the recirculating loop to keep the

medium from falling off. This is called a holding flow. As the inlet and outlet valves are opened for normal usage, called service flow, the holding flow is gradually cut off.

Bucket Strainer

The following is taken from Daido Machines, “Bucket Strainers.”

Bucket strainers are mainly installed in horizontal piping. Since the bucket strainer elements housed in the bodies can be taken out from the tops, the debris caught by the elements can be taken outside easily. Bucket strainers can be designed to suit larger piping.

Deep-Bed Filters

The following is taken from Environmental Expert, “Deep Bed Filters.”

A deep bed filter may be defined as a granular filter for removal of total suspended solids (TSS) from secondary treatment effluent using a media depth of at least four feet at a filtration rate of more than 2 gpm/ft². Coarse media is normally used to encourage deep penetration of solids into the media bed. This allows for longer filtration runtimes. Simultaneous air and water backwashes are used to ensure cleaning of the filters as required.

Secondary effluent enters a filter at the top and is evenly distributed across the entire filter. As the wastewater passes through the filter bed, suspended solids are retained and stored in the voids between the sand grains. Accumulation of solids will decrease the void space in the filter media bed. As the filtration cycle progresses, additional energy is needed to maintain the required filtration rate indicated by an increase in headloss. When the headloss reaches the maximum available level and the filtration rate cannot be maintained, the filter must be removed from service and the media cleaned.

High Efficiency Particulate Air (HEPA) Filters

The following is taken from Wikipedia, “HEPA Filters.”

High-efficiency particulate air is a type of air filter. Filters meeting the HEPA standard have many applications, including use in medical facilities, automobiles, aircraft, and homes. Filters must satisfy certain standards of efficiency such as those set by DOE. To qualify as HEPA by US government standards, an air filter must remove 99.97 percent of all particles greater than 0.3 micrometer from the air that passes through. A filter that is qualified as HEPA is also subject to interior classifications.

HEPA filters are composed of a mat of randomly arranged fibers. The fibers are typically composed of fiberglass and possess diameters between 0.5 and 2.0 micrometers (μm). Key factors affecting function are fiber diameter, filter thickness, and face velocity. The air space between HEPA filter fibers is much greater than 0.3 μm. The common assumption that a HEPA filter acts like a sieve where particles smaller than the largest opening can pass through is incorrect. Unlike membrane filters at this pore size, where particles as wide as the largest opening or distance between fibers cannot pass in between them at all, HEPA filters are designed to target much smaller pollutants and particles. These particles are trapped through a combination of the following three mechanisms:

1. Interception, where particles following a line of flow in the air stream come within one radius of a fiber and adhere to it.

2. Impaction, where larger particles are unable to avoid fibers by following the curving contours of the air stream and are forced to embed in one of them directly; this effect increases with diminishing fiber separation and higher air flow velocity.
3. Diffusion, an enhancing mechanism that is a result of the collision with gas molecules by the smallest particles, especially those below 0.1 μm in diameter, which are thereby impeded and delayed in their path through the filter. This behavior is similar to Brownian motion and raises the probability that a particle will be stopped by either of the two mechanisms above; it becomes dominant at lower air flow velocities.

Diffusion predominates below the 0.1 μm diameter particle size. Impaction and interception predominate above 0.4 μm . In between, near the most penetrating particle size 0.3 μm , diffusion and interception are comparatively inefficient. Because this is the weakest point in the filter's performance, the HEPA specifications use the retention of these particles to classify the filter.

Lastly, it is important to note that HEPA filters are designed to arrest very fine particles effectively, but they do not filter out gasses and odor molecules. Circumstances requiring filtration of volatile organic compounds, chemical vapors, cigarette, pet, and/or flatulence odors call for the use of an activated carbon (charcoal) filter instead of or in addition to a HEPA filter.

Duplex Strainers

The following is taken from Stayflow Strainers, "Duplex Strainers."

Duplex strainers are ideal when the piping system cannot be shut down for basket cleaning. There are two screened baskets that trap debris, with a lever that switches between the two, allowing one basket to be cleaned with no interruption in flow—a benefit that is sometimes crucial.

The duplex strainers are available up to 8 inch diameters with threaded or flanged connections. Standard screens are provided for water, oil, and gas service. Different screens can also be used in each of the chambers, so that different batches can use the most appropriate screen.

These strainers are usually supplied in one of four materials: iron, carbon steel, bronze, or stainless steel. Iron is used most often because it costs the least, and has good corrosion resistance in water and many other services. Carbon steel is used where higher temperature or concern with thermal or mechanical shock is an issue, which makes them popular in the oil and petrochemical industries. Bronze handles thermal and mechanical shock better than iron, and is better in some corrosive applications, but is limited in temperature range. Stainless steel is needed where corrosion could be an issue, and is widely used in the chemical, food, and pharmaceutical industries.

c. Discuss the principal application of high efficiency particulate filters and the general content of DOE-STD-3020-2005 and DOE-HDBK-1169-2003.

DOE-STD-3020-2005 establishes specifications and quality assurance (QA) requirements for HEPA filters procured to protect workers, the public, and the environment when installed in DOE nuclear facilities. It provides guidance to DOE contractors for procurement and required testing of HEPA filters used in DOE nuclear facilities. Required testing is performed by the filter manufacturer and by DOE at a designated filter test facility (FTF). The standard specifies minimum requirements to be included in contractor specifications.

As directed by the Secretary of Energy's June 4, 2001 memorandum, "100 Percent Quality Assurance Testing of HEPA Filters at the DOE Filter Test Facility," prior to use in DOE facilities, filters meeting the following criteria shall be delivered to the FTF for additional QA testing:

- HEPA filters that are used in confinement ventilation systems in category 1 and category 2 nuclear facilities that perform a safety function in accident situations, or are designated as important to safety (i.e., safety class or safety significant per DOE-STD-3009-94).
- HEPA filters necessary for habitability systems (e.g., filters that protect workers who must not evacuate in emergency situations because of the necessity to shutdown or control the situation).
- For all other applications where HEPA filters are used in confinement ventilation systems for radioactive airborne particulate, develop and document an independent, tailored filter QA testing program that achieves a high degree of fitness for service. The program should include the testing of a sample of filters at the FTF. The size of the sample to be tested should be large enough to provide sufficient statistical power and significance to assure the required level of performance.

The following is taken from DOE-HDBK-1169-2003, appendix A.

High reliance can be placed on the HEPA filter if precautions are taken in handling, storage, and installation. Inspection upon delivery, upon withdrawal from stock, and before and after installation is important. A filter unit should be inspected each time it is handled to guard against installation of a damaged item.

Packaging and Shipping

Packaging practice varies among filter unit manufacturers. Normally, units are packaged in cardboard cartons with various means of providing internal strengthening and impact resistance of the carton. A carton will usually contain one of the larger units, such as the 1,500-cfm, 24 × 24 × 11½-inch unit; or it may have two 500-cfm, 24 × 24 × 5⅞-inch units. The smaller sizes, the 125-cfm, 12 × 12 × 12⅞-inch, and the smaller units are frequently packaged in individual cardboard cartons and crated in multiples.

When a filter is placed in the carton, it is inserted so that the pleated folds are vertical to prevent damage in shipment. To prevent sagging of the pleats, vertical positioning of the pleats must be maintained during subsequent handling and storage. Most important, filter units should also be installed vertically for operation.

The shipping carton is marked with a vertical arrow and the notation "this side up" to indicate positioning of the carton in the transport vehicle. Other markings, "handle with care," "use no hooks," etc., may be found on some containers.

When a filter unit is shipped with pleats in the horizontal position, the vibration that occurs during transportation and the jarring that usually accompanies handling often cause the filter medium to split or to break at the adhesive line, which will appear as a hairline crack.

Occasionally, the manufacturer positions a filter unit improperly in the container. Cartons are often not placed in trucks according to the vertical arrow, and they are not handled consistently with the care designated. Consequently, inspection to verify that filters have been packed properly is necessary upon delivery at the destination. Experience has shown that filters should not be shipped by rail.

Receiving and Unloading

Inspection starts when a delivery of filter units reaches the purchaser, even while the load is still aboard the carrier. As the shipment is being unloaded, each carton should be inspected for external damage and improper positioning in the cargo space (i.e., the carton placed with arrow directed horizontally). Damaged cartons, including those with corners dented and those improperly oriented in the truck, should be set aside for particularly careful inspection of their contents. Damage will be more prevalent when filter units are loaded with mixed cargoes or are shipped in a partially loaded carrier.

The filter unit must be removed carefully from its carton. The acceptable method for removal is to open the top flaps of the container after removing the sealing tape. With flaps folded back, the carton should be inverted or upended gently to place the exposed end of the filter unit on a flat surface, preferably the floor.

The surface must be clear of nuts, bolts, and similar protrusions. Then withdraw the carton from the filter unit. Attempts to remove the filter unit from the carton by grasping below the exposed filter case can result in irreparable damage if fingers puncture the delicate filter medium attached immediately below the case.

Shipping

HEPA filters should be shipped under controlled conditions insofar as practicable. Too often, after the cartons have been carefully arranged in a truck-trailer body, the shipper removes them at an interchange station, stacks them temporarily in the terminal (under completely uncontrolled conditions), and then stacks them into another truck-trailer. Handling under such conditions is usually careless, and attention to proper orientation of the cartons may be nonexistent. As a minimum, it is recommended that cartons be steelbanded to a skid or pallet, no more than 6½ feet high, in the specified vertical orientation. Plywood crates are preferred. Skids (pallets) must not be stacked one above the other unless bracing is provided in the truck-trailer body or railroad car to prevent the weight of the upper load from resting on the lower. This will force the shipper to keep the cartons in their proper orientation and prevent the shipper from throwing or dropping them indiscriminately.

Another control is to require that the filters be packed properly in a sealed truck-trailer body or in a sealed containerized-freight unit, not to be opened until arrival at the specified delivery point. The trailer or containerized-freight unit should be unloaded by personnel employed at the delivery site who have been thoroughly instructed in the proper care and handling of HEPA filters. Mixed-load shipments should be avoided.

Storage

Following receipt and inspection, the filter unit should be repacked carefully in the carton in which it was shipped and received. All packing material for internal strengthening of the carton and for protection of the filter unit should be replaced properly. Pleats of the filter unit should be positioned to conform to the orientation marking on the carton; this should be done routinely whether the filter unit will be installed immediately or whether it will be stored.

Cartons of filter units should be positioned in storage to conform to the vertical arrow, and the manufacturer's recommendations for storage heights should be followed. When recommendations are not available, filter units 24 × 24 × 11½ inches and 24 × 24 × 5⅞ inches

should be stacked not more than three filter units high. Alternate the position of each level so as to not have one filter support the one above it.

Mixing other items and materials with filter units in storage should be avoided to prevent damage to the filter units. Recommended aisle widths consistent with good warehousing practice should be provided to reduce damage of filter units from materials-handling equipment and other traffic. Filter units should not be stored in locations where they will be exposed to dampness, excessive heat or cold, or rapidly changing temperatures. A National Quality Assurance-1 Level B storage or equivalent should be used.

Handling

Mechanical warehousing equipment is recommended for handling large quantities of filter units. Skids and pallets should be used to provide a flat bed for movement of the units.

Chains, slings, and hooks obviously must not be used. The cartons should be placed on the pallet so that the arrow on the carton points vertically.

In physically handling a packaged filter unit, a person must make certain that the carton is picked up at opposite corners and deposited carefully on the floor or other surface. The carton should not be dropped or jarred. Any filter unit dropped, whether or not in the carton, should be reexamined for damage.

When a filter unit is lifted, it must be grasped only along the outer surface of the case. Even slight contact of fingers at almost any point within the case can puncture the filter medium.

A handle or grip is sometimes attached permanently to the wood filter case for ease of installation and removal of the filter unit. In such instances, care must be taken in attaching the handle. Screws should not be pounded for starting, and nails should never be used. The recommended method is to drill starting screw holes, making certain that the drill and the length of screws do not penetrate through the frame and pierce the filter medium attached (screws must not be longer than $\frac{3}{4}$ inches). Pounding may crack the filter medium and possibly loosen the adhesive seal that bonds the filter pack within the frame. Attachment of a handle to a metal-frame filter unit is not recommended.

Filter units should be kept in shipping cartons when moved from one location to another. When transferred for installation, the units should be unloaded at a point that, so far as practicable, will reduce physical handling. Filter units should remain in cartons until ready for installation and then should be unpacked.

If for any reason an unpackaged filter unit must be placed with its face on the floor or other surface, the surface must be cleared of every object or irregularity that might damage the filter pack.

Installation

Personnel responsible for installation of the filter unit must be carefully instructed in proper handling technique. They should know that the filter pack within the frame is delicate and must not be damaged during installation. Equally important is that the filter unit must be installed so that unfiltered air will not leak past the unit. The following installation procedure, as a minimum, should be used:

- Carefully remove filter unit from shipping carton.

- Carefully inspect both faces of the filter unit for cracks in the filter medium, for damage of separators, and for separation of the filter pack at the frame.
- Ensure that the gasket is cemented firmly to the frame and that the gasket pieces are butted or mated at the joints.
- The gasket must be compressed firmly. Compression should be applied evenly and equally at all points in increments of 5 feet-pounds or less, with the filter frame completely covering the opening.
- Install the filter with pleats and separators in the vertical position. This will eliminate sagging of pleats from accumulated weight of materials stopped by the filter unit.

d. Identify and describe the hazards associated with high efficiency particulate filters, including any fire safety concerns.

The following is taken from DOE-STD-1066-99.

To be listed by Underwriters Laboratories under UL-586 as a high efficiency particulate air filter unit, HEPA filters are required to 1) withstand 750°F air for 5 minutes at rated airflow capacity and have greater than 97 percent di-octyl phthalate efficiency, and 2) withstand a spot-flame test in which a Bunsen burner flame is placed on the filter core with no after burning when the flame is removed.

However, it can be noted that there is a rapid decrease in the tensile strength of the filter media at about 450°F, and when temperatures get above 800°F the fibers in the filters begin to break and curl up, leaving pinholes in the filter media. Extended exposure to temperatures above 800°F will cause destruction of the case in wood-cased filters and warping of the case in steel-cased filters, resulting in bypassing of unfiltered air.

Although HEPA filters can withstand 750°F temperature for a very limited time duration, they should not be subjected to indefinite exposure temperatures higher than 275°F. Longer filter life and more reliable service as well as an operational safety factor can be obtained when normal operating temperatures are below 200°F and high temperature extremes are avoided.

Continuous operation of HEPA filters at higher temperatures is limited primarily by the filter sealant, used to seal the filter core into the filter case. At higher temperatures, the sealants lose their strength, causing filter failure. For example, standard urethane seals are suitable for service at 250°F, while some silicone seals can withstand 500°F.

Since different sealants are available and different filter manufacturers rate their filters for different temperatures, the best practice is for ventilation system designers and operators to determine the manufacturer's limiting continuous service temperature if continuous operation at high temperatures is necessary.

16. Mechanical systems personnel shall demonstrate a working level knowledge of the basic components, operations, and theory of hydraulic systems.

a. Define the following terms and discuss their relationship in hydraulic systems:

- Force
- Work
- Pressure
- Reservoir

- **Accumulator**
- **Actuator**

Force

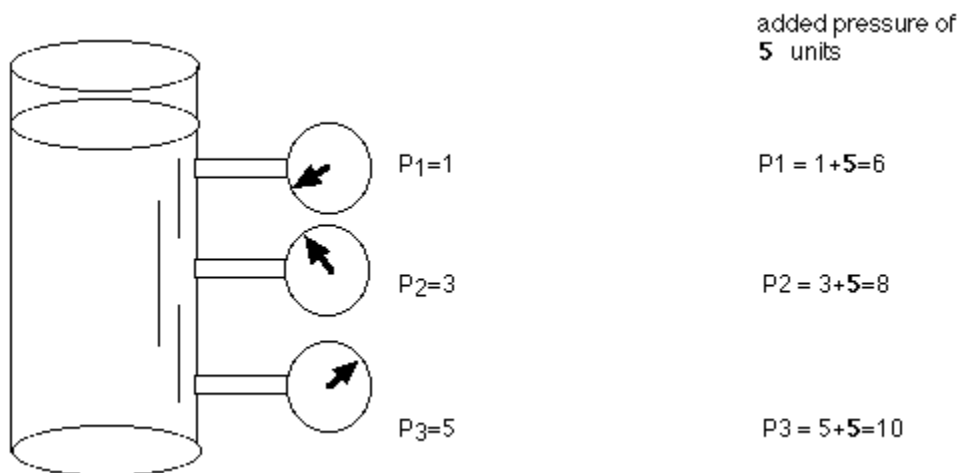
The following is taken from the National Aeronautics and Space Administration, “Pascal’s Principle and Hydraulics.”

Hydraulic systems use an incompressible fluid, such as oil or water, to transmit forces from one location to another within the fluid. Most aircraft use hydraulics in their braking systems and landing gear. Pneumatic systems use compressible fluid, such as air, in their operation. Some aircraft use pneumatic systems for their brakes, landing gear, and movement of flaps.

Pascal’s law states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container.

A container, as shown in figure 59, contains a fluid. There is an increase in pressure as the length of the column of liquid increases, due to the increased mass of the fluid above.

For example, in figure 59, P3 would be the highest value of the three pressure readings, because it has the highest level of fluid above it.



Source: National Aeronautics and Space Administration, *Pascal’s Principle and Hydraulics*

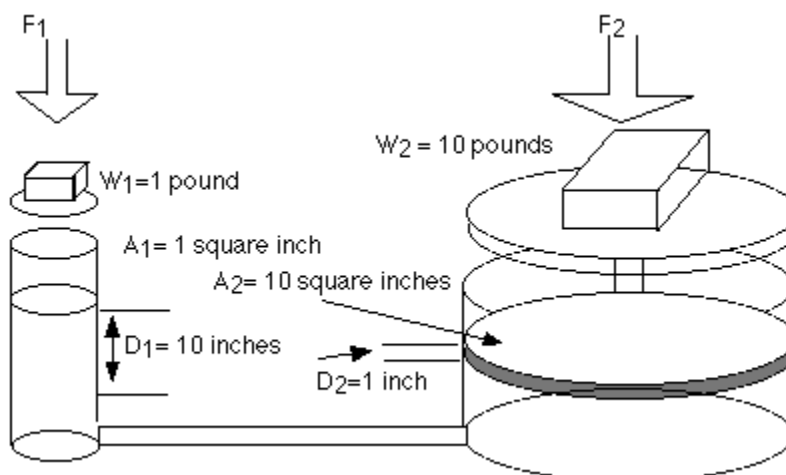
Figure 59. Pascal’s law

If the above container had an increase in overall pressure, that same added pressure would affect each of the gauges (and the liquid throughout) the same. For example if P1, P2, P3 were originally 1, 3, and 5 units of pressure, and 5 units of pressure were added to the system, the new readings would be 6, 8, and 10.

Applied to a more complex system in figure 60, such as a hydraulic car lift, Pascal’s law allows forces to be multiplied. The cylinder on the left shows a cross-section area of 1 square inch, while the cylinder on the right shows a cross-section area of 10 square inches. The cylinder on the left has a weight (force) of 1 pound acting downward on the piston, which lowers the fluid 10 inches. As a result of this force, the piston on the right lifts a 10 pound weight a distance of 1 inch.

The 1 pound load on the 1 square inch area causes an increase in pressure on the fluid in the system. This pressure is distributed equally throughout and acts on every square inch of the 10

square inch area of the large piston. As a result, the larger piston lifts up a 10 pound weight. The larger the cross-section area of the second piston, the larger the mechanical advantage, and the more weight it lifts.



Source: National Aeronautics and Space Administration, *Pascal's Principle and Hydraulics*

Figure 60. Pascal's law on a complex system

The formulas that relate to this are shown below:

$$P_1 = P_2 \text{ (since the pressures are equal throughout).}$$

Since pressure equals force per unit area, then it follows that

$$F_1/A_1 = F_2/A_2$$

It can be shown by substitution that the values shown above are correct,

$$1 \text{ pound} / 1 \text{ square inches} = 10 \text{ pounds} / 10 \text{ square inches}$$

Because the volume of fluid pushed down on the left side equals the volume of fluid that is lifted up on the right side, the following formula is also true:

$$V_1 = V_2$$

by substitution,

$$A_1 D_1 = A_2 D_2$$

A = cross sectional area

D = the distance moved

or

$$A_1/A_2 = D_2/D_1$$

This system can be thought of as a simple machine (lever), since force is multiplied. The mechanical advantage can be found by rearranging terms in the above equation to

$$\text{Mechanical Advantage (IMA)} = D_1/D_2 = A_2/A_1$$

For the sample problem above, the IMA would be 10:1 (10 inches/1 inch or 10 square inches /1 square inch).

Work

The following is taken from Wikipedia, “Work.”

In physics, a force is said to do work when it acts on a body so that there is a displacement of the point of application, however small, in the direction of the force. Thus a force does work when there is movement under the action of the force.

The term work was introduced in 1826 by the French mathematician Gaspard-Gustave Coriolis. The SI unit of work is the joule.

The work done by a constant force of magnitude F on a point that moves a distance d in the direction of the force is the product,

$$W = Fd$$

For example, if a force of 10 newton ($F = 10 \text{ N}$) acts along a point that travels 2 meters ($d = 2 \text{ m}$), then it does the work $W = (10 \text{ N})(2 \text{ m}) = 20 \text{ N m} = 20 \text{ J}$. Another example is lifting two weights that have the same mass one story in height. This requires twice the work as lifting one weight the same one story. Also, lifting one weight two stories requires the same work as lifting two weights one story.

The concepts of work and energy are closely related. According to the work-energy theorem the work done by all forces acting on a rigid body is equal to that body's change in kinetic energy. Work is a transfer of energy between systems mediated by a force. Work thus has the same physical dimension and units as energy. In thermodynamics, work is a generalization of mechanical work encompassing all energy transfer except heat.

Pressure

The following is taken from Princeton University, “Pressure.”

Pressure is a stress. It is a scalar given by the magnitude of the force per unit area. In a gas, it is the force per unit area exerted by the change of momentum of the molecules impinging on the surface. Newton's second law explains that a net resultant force will cause a change of momentum in a body, and that the rate of change of momentum is equal to the applied force. It is a vector relationship, so that even if the magnitude of the momentum is unchanged, a change in the direction of motion requires a resultant force. The impact of a gas molecule on a solid surface is an elastic impact so that its momentum magnitude and energy are conserved. However, because its direction of motion changes on impact, a resultant force must have been exerted by the solid surface on the gas molecule. Conversely, an equal but opposite force was exerted by the gas molecule on the solid surface. If a very small area of the surface of the solid is considered, so that over a short time interval very few molecules collide with the solid over this area, then the force exerted by the gas molecules will vary sharply with time. When a sufficiently large area is considered, so that the number of collisions on the surface during the interval is large, then the average force that acts on the solid surface by the molecules is constant. It is this force, acting on the surface of the solid, which is called the force due to pressure.

In practice, the area need only be larger than about 10 times $(\text{mean free path})^2$, so that pressure is a continuum property, meaning that for areas of engineering interest, which are almost always much larger than areas measured in terms of the mean free path, the pressure does not have any

measurable statistical fluctuations caused by molecular motions. A distinction between microscopic properties and the macroscopic properties of a fluid can be made; the microscopic properties relate to the behavior on a molecular scale, and the macroscopic properties pertain to the behavior on an engineering scale.

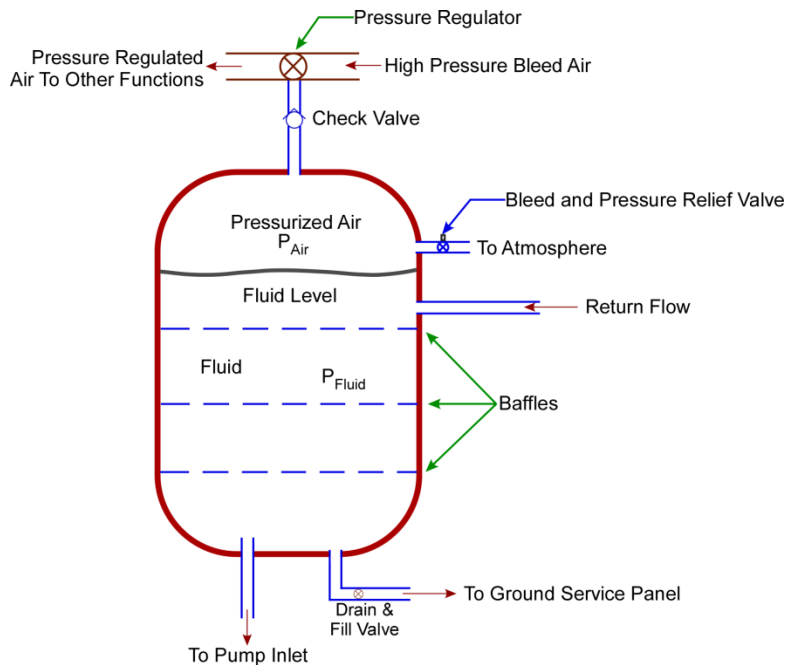
Consider the line of action of the force due to pressure. On a molecular level, a flat solid surface is never flat. However, it is flat on average, so that, on average, for each molecule that rebounds with some component of momentum along the surface, another rebounds with the same component of the momentum in the opposite direction. The average momentum of the molecules in the direction along the surface will not change during their impact with the surface. Therefore, the average force due to pressure acts in a direction that is purely normal to the surface. Furthermore, since the momentum of the molecules is randomly distributed in space, the magnitude of the force due to pressure should be independent of the direction of the surface on which it acts. For instance, a thin flat plate in air will experience a zero resultant force due to air pressure since the forces due to pressure on its two sides have the same magnitude (the pressure is independent of the orientation of the surface on which it acts) and they point in opposite directions. That pressure is isotropic.

An important property of pressure is that it is transmitted through the fluid. When an inflated bicycle tube is pressed at one point, for example, the pressure increases at every other point in the tube. Measurements show that the increase is the same at every point and equal to the applied pressure. For example, if an extra pressure of 5 psi were suddenly applied at the tube valve, the pressure would increase at every point of the tube by exactly this amount. This property of transmitting pressure undiminished is a well established experimental fact, and it is a property possessed by all fluids. The transmission does not occur instantaneously, but at a rate that depends on the speed of sound in the medium and the shape of the container. The speed of sound is important because it measures the rate at which pressure disturbances propagate (sound is just a pressure disturbance travelling through a medium). The shape of the container is important because pressure waves refract and reflect off the walls of the container and increase the distance and time the pressure waves need to travel. This phenomenon should be familiar to anyone who has experienced the imperfect acoustics of a poorly designed concert hall.

Reservoir

The following is taken from Design Aerospace, “Reservoir.”

All hydraulic systems have a reservoir. A reservoir is similar to an accumulator, except that the fluid pressure is constant over all fluid levels. A reservoir performs several functions. First and foremost, the reservoir holds fluid not required by the system under any given operating condition and accounts for fluid capacity needs over time in the system. Fluid volume needs will vary during different operational scenarios, such as gear extension. Secondly, the reservoir provides for thermal expansion of the fluid over the operational temperature range of the system. Thirdly, the reservoir provides fluid to the inlet side of the hydraulic pump. Reservoir pressurization levels are a critical aspect of reservoir installations.



Source: *Design Aerospace, Reservoir*

Figure 61 . Reservoir

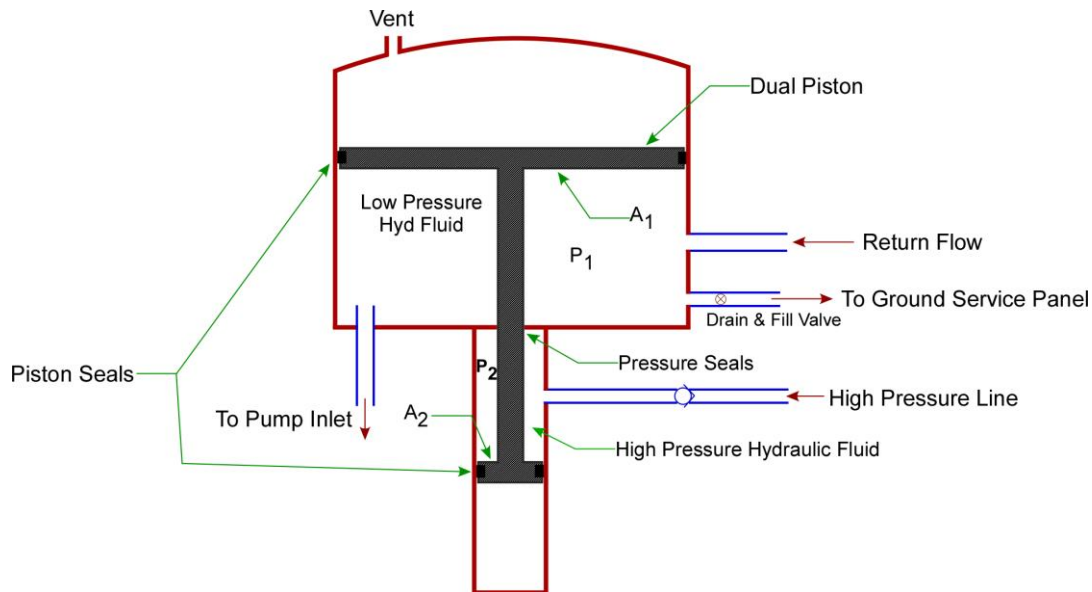
gas reservoir. For a gas reservoir a low pressure gas source is required. Engine bleed air, fed through a pressure regulator, is often used for pressurized gas reservoirs. A fixed pressure source, such as a charged nitrogen bottle, is another possible configuration. A bleed air configuration is shown in figure 61. The pressure regulator setting will be in the 50-200 psi range.

In the pressurized gas reservoir, $P_{Air} = P_{Fluid}$. The air does not mix with the fluid due to the density differences. However, air can escape from the fluid into the air providing some system removal of air. This characteristic does not replace system bleeding.

For a gas reservoir, the amount of gas should be sufficient to provide uninterrupted flow of fluid to the pump under all operating scenarios and vehicle attitudes. For example, a high nose up attitude should not cause fluid to block the air inlet port. In addition, there should be enough gas to absorb high surge pressure that might occur with high return flow to the reservoir. Surge pressure should be less than the pressure relief valve setting and, of course, be much less than the proof pressure rating of the reservoir. The minimum recommended gas volume is 10 percent of the total reservoir volume. The inlet line should be located at a place so that inlet flow does not create a vortex within the reservoir or cause foaming of the fluid. The fluid spin caused through vortex action will push fluid to the outside and can starve the reservoir outlet by opening the outlet up to air. Baffles or diverters can be used in the reservoir as part of the reservoir design to prevent vortexes or foaming. Lastly, if the air pressurization source is lost there should be a means to allow atmospheric air to enter the gas chamber of the reservoir.

Reservoirs consist of a container or volume, fluid inlet port, fluid outlet port, fill/drain port, and a means to pressurize the fluid in the volume. Reservoirs used in aerospace are pressurized using pressurized gas, through a piston that has high pressure hydraulic pressure on one side, or through a mechanical piston and spring. The terms separated and non-separated are used with reservoirs. Separated means that the reservoir fluid is separated from the pressure source though a separation device. Non-separated refers to a gas pressurized reservoir where there is no separation between the fluid and the gas.

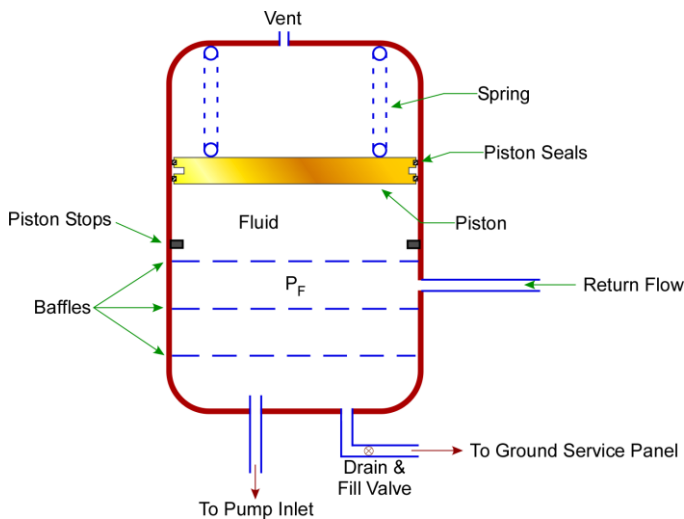
Figure 61 shows a pressurized



Source: Design Aerospace, Reservoir

Figure 62. Bootstrap reservoir

A bootstrap reservoir is shown in figure 62. A bootstrap uses a differential area piston where high pressure hydraulic pressure from the pump outlet is applied to the small area of the piston. This produces a low pressure on the reservoir side of the piston. A major advantage of bootstrap reservoirs is that reservoir pressurization is maintained during aggressive flight maneuvers, including negative g flight. Additional hydraulic plumbing and some components are required for bootstrap reservoir implementation. Also, note the check valve in the high pressure line. The purpose of this check valve is to maintain reservoir pressure after the pump has shut down so that the pump inlet is maintained when the engine driven pump is not rotating. Accumulators may also be used in this circuit to assist in maintaining pump inlet pressure. The accumulator will be between the check valve and the reservoir.



Source: Design Aerospace, Reservoir

Figure 63. Mechanical piston reservoir

When the reservoir is at equilibrium $P_1 A_1 = P_2 A_2$. Since $A_1 \gg A_2$, $P_1 \ll P_2$. The differential piston areas are set by the pump nominal pump outlet pressure and the required level of reservoir fluid pressure.

Figure 63 shows a mechanical piston reservoir. In this reservoir a spring with an appropriate preload and a low spring rate pushes on a piston and provides a fairly constant reservoir pressure.

Metal bellows is another (relatively new) type of reservoir. A metal bellows reservoir would be similar to a metal bellows accumulator. Operation of a metal bellows accumulator would be similar to a piston/spring reservoir type.

Accumulator

The following is taken from Wikipedia, “Hydraulic Accumulator.”

A hydraulic accumulator is a pressure storage reservoir in which a non-compressible hydraulic fluid is held under pressure by an external source. The external source can be a spring, a raised weight, or a compressed gas. An accumulator enables a hydraulic system to cope with extremes of demand using a less powerful pump, to respond more quickly to a temporary demand, and to smooth out pulsations. It is a type of energy storage device.

Compressed gas accumulators, also called hydro-pneumatic accumulators, are by far the most common type.

Actuator

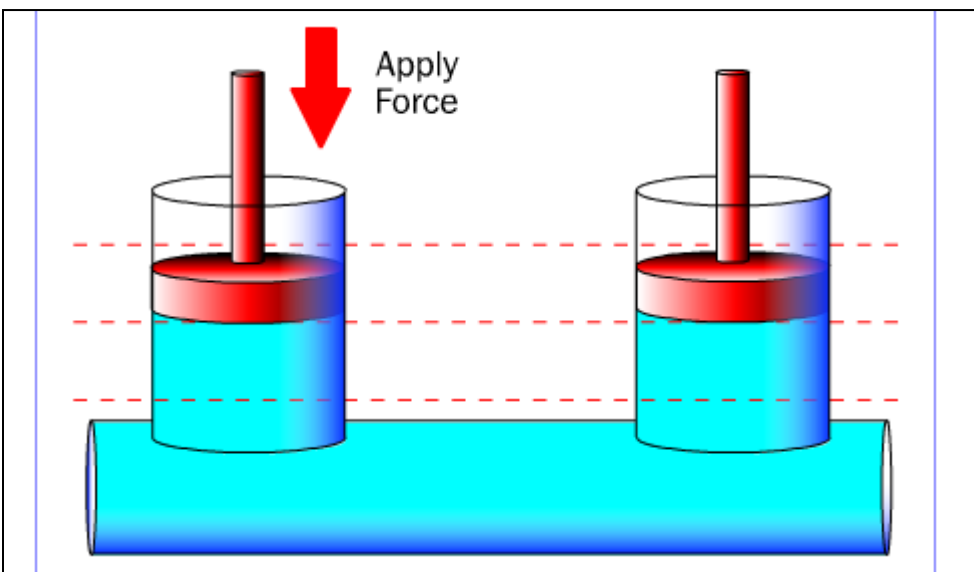
The following is taken from Wikipedia, “Actuator.”

An actuator is a type of motor for moving or controlling a mechanism or system. It is operated by a source of energy, usually in the form of an electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into some kind of motion. An actuator is the mechanism by which an agent acts upon an environment. The agent can be either an artificial intelligence agent or any other autonomous being (human, other animal, etc.).

b. Describe the basic operation of a hydraulic system.

The following is taken from How Stuff Works, “How Hydraulic Machines Work.”

The basic idea behind any hydraulic system is very simple: Force that is applied at one point is transmitted to another point using an incompressible fluid. The fluid is almost always an oil of some sort. The force is almost always multiplied in the process. Figure 64 shows the simplest



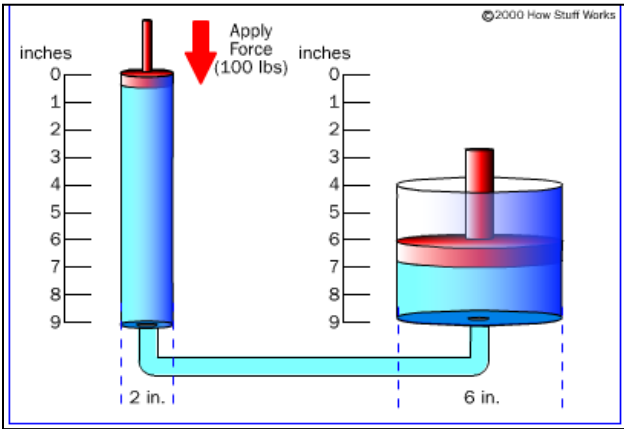
Source: How Stuff Works, How Hydraulic Machines Work

Figure 64. A simple hydraulic system

possible
hydraulic
system:

Two pistons (red) fit into two glass cylinders filled with oil (light blue) and are connected to one another with an oil-filled pipe. If a downward force is applied to one piston, then the force is transmitted to the second piston through the oil in

the pipe. Since oil is incompressible, the efficiency is very good. Almost all of the applied force appears at the second piston. The great thing about hydraulic systems is that the pipe connecting the two cylinders can be any length and shape, allowing it to snake through all sorts of things separating the two pistons. The pipe can also fork, so that one master cylinder can drive more than one slave cylinder if desired.



Source: *How Stuff Works, How Hydraulic Machines Work*

Figure 65. Hydraulic multiplication

diameter, while the piston on the right is 6 inches in diameter. The area of the two pistons is $\pi * r^2$. The area of the left piston is therefore 3.14, while the area of the piston on the right is 28.26. The piston on the right is 9 times larger than the piston on the left. What that means is that any force applied to the left-hand piston will appear 9 times greater on the right-hand piston. So if a 100-pound downward force is applied to the left piston, a 900-pound upward force will appear on the right. The only catch is that the left piston will have to be depressed 9 inches to raise the right piston 1 inch.

c. Discuss how energy in a hydraulic system is converted to work.

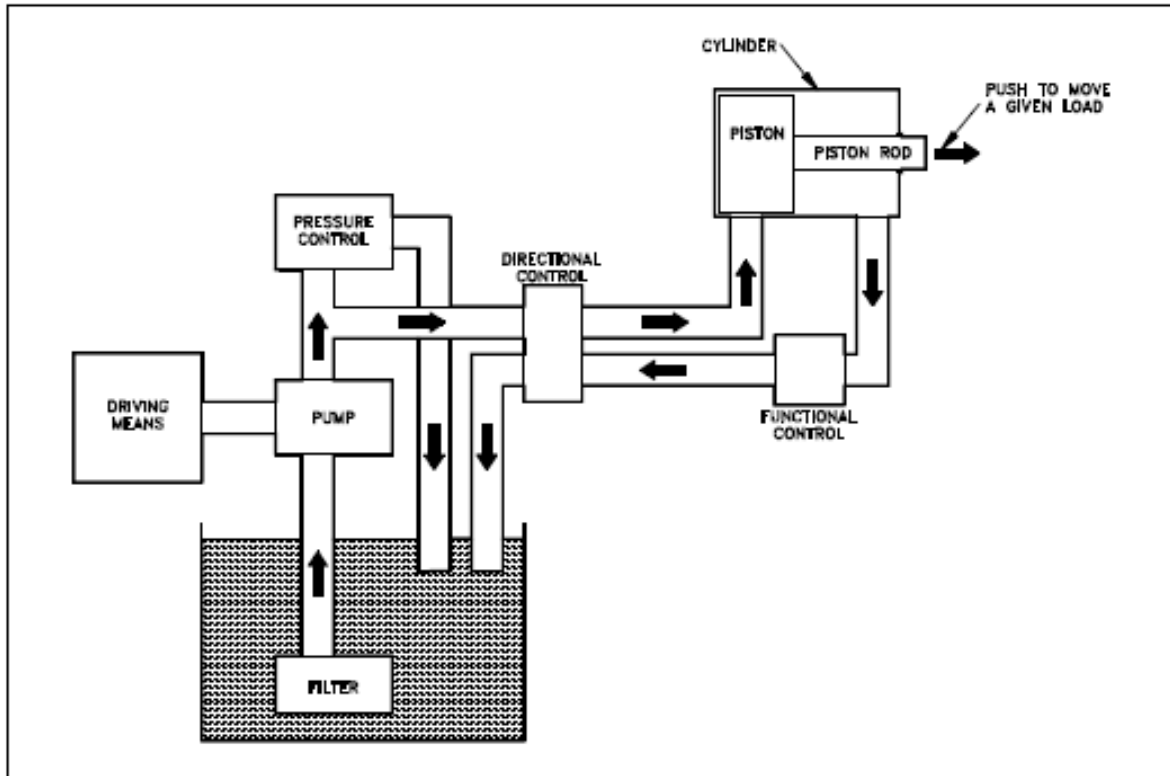
The following is taken from DOE-HDBK-1018/2-93.

The operation of a typical hydraulic system is illustrated in figure 66. Oil from a tank or reservoir flows through a pipe into a pump. Often a filter is provided on the pump suction to remove impurities from the oil. The pump, usually a gear-type PD pump, can be driven by an electric motor, air motor, gas or steam turbine, or an internal combustion engine. The pump increases the pressure of the oil. The actual pressure developed depends upon the design of the system.

Most hydraulic systems have some method of preventing overpressure. As seen in figure 66, one method of pressure control involves returning hydraulic oil to the oil reservoir. The pressure control box shown on figure 66 is usually a relief valve that provides a means of returning oil to the reservoir upon overpressurization.

In hydraulic systems it is very easy to add force multiplication (or division) to the system. In a hydraulic system, just change the size of one piston and cylinder relative to the other, as shown in figure 65:

The piston on the right has a surface area nine times greater than the piston on the left. When force is applied to the left piston, it will move nine units for every one unit that the right piston moves, and the force is multiplied by nine on the right-hand piston. To determine the multiplication factor, start by looking at the size of the pistons. Assume that the piston on the left is 2 inches in



Source: DOE-HDBK-1018/2-93

Figure 66. Basic hydraulic system

The high pressure oil flows through a control valve (directional control). The control valve changes the direction of oil flow, depending on the desired direction of the load. In figure 66 the load can be moved to the left or to the right by changing the side of the piston to which the oil pressure is applied. The oil that enters the cylinder applies pressure over the area of the piston, developing a force on the piston rod. The force on the piston rod enables the movement of a load or device. The oil from the other side of the piston returns to a reservoir or tank.

Video 45. Work and energy

<http://www.bing.com/videos/search?q=Work+and+Energy+&view=detail&mid=A7DE8BC42A74ACCA3219A7DE8BC42A74ACCA3219&first=0>

d. Discuss the purpose and basic construction of a hydraulic reservoir.

The following is taken from Wikipedia, “Hydraulic Machinery.”

The hydraulic fluid reservoir holds excess hydraulic fluid to accommodate volume changes from cylinder extension and contraction, temperature driven expansion and contraction, and leaks. The reservoir is also designed to aid in separation of air from the fluid and also work as a heat accumulator to cover losses in the system when peak power is used. Design engineers are always pressured to reduce the size of hydraulic reservoirs, while equipment operators always appreciate larger reservoirs. Reservoirs can also help separate dirt and other particulate from the oil, as the particulate will generally settle to the bottom of the tank.

Some designs include dynamic flow channels on the fluid’s return path that allow for a smaller reservoir.

e. Discuss the purpose and basic construction of a hydraulic accumulator.

The following is taken from Wikipedia, “Hydraulic Machinery.”

Hydraulic energy storage systems store energy by compressing air, similar to a battery storing energy in an electric circuit. The need for two storage tanks and two accumulators can be eliminated: the entire hydraulic energy storage system is an open loop. The storage requirement is smaller because depressurized air is not stored. The hydraulic open loop accumulator works by drawing air in from the atmosphere and expelling air out to the atmosphere. A separate hydraulic pump maintains the pressure balance of the air by increasing the amount of hydraulic fluid in the system. This results in a steady pressure of air and up to 24 times the energy density of a standard hydraulic accumulator.

This hydraulic energy storage system has applications in energy storage for wind turbines, regenerative braking systems for hybrid cars that could partially power the car, and energy storage for power construction equipment.

f. Identify and discuss the hazards associated with hydraulic systems and their components.

The following is taken from Colorado State University, “Hydraulic System Safety.”

Hydraulic systems must store fluid under high pressure.

Three kinds of hazards exist: burns from the hot, high pressure spray of fluid; bruises, cuts or abrasions from flailing hydraulic lines; and injection of fluid into the skin.

Safe hydraulic system performance requires general maintenance.

Proper coupling of high and low pressure hydraulic components and pressure relief valves are important safety measures.

Hydraulic systems are popular on many types of equipment because they reduce the need for complex mechanical linkages and allow remote control of numerous operations. Hydraulic systems are used to lift implements, to change the position of implement components, to operate remote hydraulic motors; and to assist steering and braking.

To do their work, hydraulic systems must store fluid under high pressure, typically 2,000 pounds or more per square inch. One hazard comes from removing or adjusting components without releasing the pressure. The fluid, under tremendous pressure, is also hot. The worker then is exposed to three kinds of hazards: burns from hot, high-pressure fluid; bruises, cuts or abrasions from flailing hydraulic lines; and injection of fluid into the skin.

Many systems store hydraulic energy in accumulators. These accumulators are designed to store oil under pressure when the hydraulic pump cannot keep up with demand, when the engine is shut down, or when the hydraulic pump malfunctions. Even though the pump may be stopped or an implement disconnected, the system is still under pressure. To work on the system safely, relieve the pressure first.

Probably the most common injury associated with hydraulic systems is the result of pinhole leaks in hoses. These leaks are difficult to locate. A person may notice a damp, oily, dirty place near a hydraulic line. Not seeing the leak, the person runs a hand or finger along the line to find

it. When the pinhole is reached, the fluid can be injected into the skin as if from a hypodermic syringe.

Immediately after the injection, the person experiences only a slight stinging sensation and may not think much about it. Several hours later, however, the wound begins to throb and severe pain begins. By the time a doctor is seen, it is often too late, and the individual loses a finger or entire arm.

Unfortunately, this kind of accident is not uncommon. To reduce the chances of this type of injury, run a piece of wood or cardboard along the hose (rather than fingers) to detect the leak.

Another hazard is improper coupling of low- and high-pressure hydraulic components. Do not connect a high-pressure pump to a low-pressure system. Do not incorporate a low-pressure component, hose or fitting into a high-pressure system. Component, hose or fitting ruptures are likely to occur.

Pressure relief valves incorporated into the hydraulic system will avoid pressure buildups during use. Keep these valves clean and test them periodically to ensure correct operation.

An improperly maintained hydraulic system can lead to component failures. Safe hydraulic system performance requires general maintenance:

- Periodically check for oil leaks and worn hoses.
- Keep contaminants from hydraulic oil and replace filters periodically.
- Coat cylinder rods with protective lubricants to avoid rusting.

Follow these rules for safe hydraulics operation:

- Always lower the hydraulic working units to the ground before leaving the machine.
- Park the machinery where children cannot reach it.
- Block up the working units when working on the system while raised; do not rely on the hydraulic lift.
- Never service the hydraulic system while the machine engine is running unless absolutely necessary (bleeding the system).
- Do not remove cylinders until the working units are resting on the ground or securely on safety stands or blocks; shut off the engine.
- When transporting the machine, lock the cylinder stops to hold the working units solidly in place.
- Before disconnecting oil lines, relieve all hydraulic pressure and discharge the accumulator (if used).
- Be sure all line connections are tight and lines are not damaged; escaping oil under pressure is a fire hazard and can cause personal injury.
- Some hydraulic pumps and control valves are heavy. Before removing them, provide a means of support such as a chain hoist, floor jack or blocks.
- When washing parts, use a nonvolatile cleaning solvent.
- To ensure control of the unit, keep the hydraulics in proper adjustment.

17. Mechanical systems personnel shall demonstrate a working level knowledge of the components, operation, and theory of pneumatic systems.

a. Define the following terms and discuss their relationship:

- Dew point
- Dehydrator
- Dew point indicator
- Actuator

Dew Point

The following is taken from Parr, E. Andrew, *Hydraulics and Pneumatics*, Second Edition.

Moisture content of unsaturated air is referred to by relative humidity, which is defined as:

$$\text{Relative humidity} = \frac{\text{water content per cubic meter}}{\text{maximum water content per cubic meter}} \times 100\%$$

Relative humidity is dependent on temperature and pressure of the air. Suppose air at 30°C contains 20 grams of water vapor. This corresponds to 67 percent humidity. If the air is allowed to cool to 20°C, it can only hold 17 grams of water vapor and is now saturated (100 percent relative humidity). The excess 3 grams condenses out as liquid water. If the air is cooled further to 10°C, a further 8 grams condenses out.

The temperature at which air becomes saturated is referred to as the “dew point.” For example, air with 17.3 grams of water vapor per cubic meter has a dew point of 20°C.

Dehydrator (Dryer)

The following is taken from Vaisala, “Dew Point in Compressed Air.”

Dew point temperatures in compressed air range from ambient down to -112°F, sometimes lower in special cases. Compressor systems without air drying capability tend to produce compressed air that is saturated at ambient temperature. Systems with refrigerant dryers pass the compressed air through some sort of cooled heat exchanger, causing water to condense out of the air stream. These systems typically produce air with a dew point no lower than 23°F. Desiccant drying systems absorb water vapor from the air stream and can produce air with a dew point of -40°F and drier if required.

Dew Point Indicator

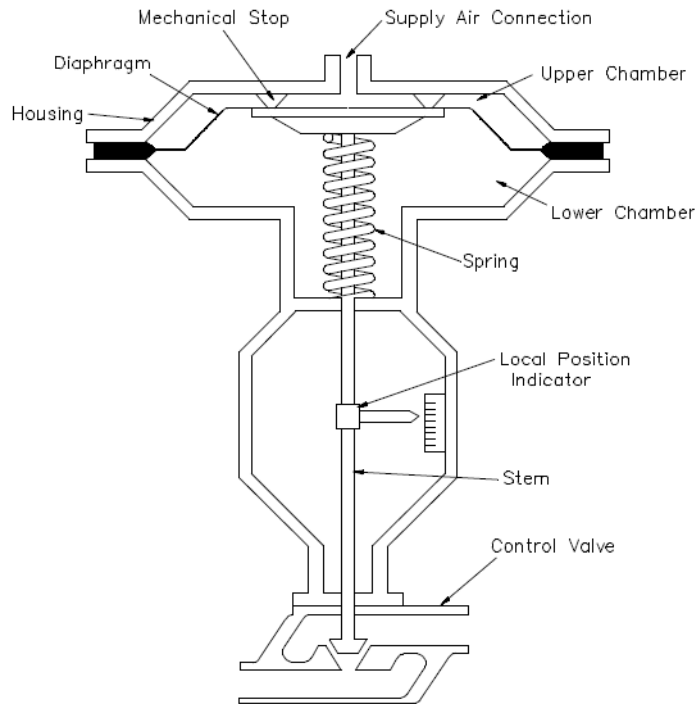
The following is taken from Van Air Systems, “Dew Point Monitors.”

Excessive moisture in compressed air lines corrodes pneumatic equipment and system piping, normally the most expensive component of an air system. Moisture also contaminates sensitive instruments and processes, leading to preventable downtime. Dew point monitors [indicators] verify the performance of air dryers by analyzing the water vapor content of compressed air. In the event of an elevated moisture level, dew point monitors quickly alert plant personnel in order to minimize maintenance expenses.

Actuator

The following is taken from DOE-HDBK-1018/2-93.

A simplified diagram of a pneumatic actuator is shown in figure 67. It operates by a combination of force created by air and spring force. The actuator positions a control valve by transmitting its motion through the stem.



Source: DOE-HDBK-1018/2-93

Figure 67. Pneumatic actuator

A rubber diaphragm separates the actuator housing into two air chambers. The upper chamber receives supply air through an opening in the top of the housing.

The bottom chamber contains a spring that forces the diaphragm against mechanical stops in the upper chamber. Finally, a local indicator is connected to the stem to indicate the position of the valve.

The position of the valve is controlled by varying supply air pressure in the upper chamber. This results in a varying force on the top of the diaphragm. Initially, with no supply air, the spring forces the diaphragm upward against the mechanical stops and holds the valve fully open. As supply air pressure is increased from zero, its force on top of the diaphragm begins to overcome the opposing force of the spring. This causes the diaphragm to move downward and the control valve to close. With increasing supply air pressure, the diaphragm will continue to move downward and compress the spring until the control valve is fully closed. Conversely, if supply air pressure is decreased, the spring will begin to force the diaphragm upward and open the control valve. Additionally, if supply pressure is held constant at some value between zero and maximum, the valve will position at an intermediate position. Therefore, the valve can be positioned anywhere between fully open and fully closed in response to changes in supply air pressure.

b. Describe the basic operation of a pneumatic system.

The following is taken from eHow, "Principles of Pneumatic Systems."

Pneumatics is basically a method to turn electricity into mechanical motion using compressed gasses instead of motors or electromagnets. For many applications, this is much more efficient and practical. Systems typically include an air compressor, which stores compressed air in a cylinder and releases it under electric control. The compressed gas is almost always ordinary air because it is free and non-toxic. Often the air is slightly modified by taking out some of the water vapor and adding a small amount of atomized oil to make the gas more machine friendly.

Pneumatics systems are widely used for power tools. The power tool that an automobile mechanic uses to take off the lug nuts that hold a tire onto the hub is one example. The mechanic can easily take off even the toughest nuts in just a few seconds. There are dozens of other pneumatic power tools in dentistry, carpentry, machine shops, and laboratories. Other applications include jackhammers, the cylinder delivery systems used by some banks, and various launchers and guns designed to propel objects.

The following is taken from DOE-HDBK-1018/2-93.

c. Discuss how energy in a pneumatic system is converted to work.

The stored energy in the air system is applied to actuators, pistons, or other mechanical components to operate these components. The air operates these components to allow system operation.

d. Discuss the hazardous relationship between high-pressure air and oil.

The following is taken from DOE-HDBK-1018/2-93.

Great care should be taken to keep contaminants from entering air systems. This is especially true for oil. Oil introduced in to an air compressor can be compressed to the point where detonation takes place in a manner similar to that which occurs in a diesel engine. This detonation can cause equipment damage and personnel injury.

e. Identify and discuss the general hazards associated with pneumatic systems and their components and the over-pressurization of these systems.

The following is taken from DOE-HDBK-1018/2-93.

People often lack respect for the power in compressed air because air is so common and is often viewed as harmless. At sufficient pressures, compressed air can cause serious damage if handled incorrectly. To minimize the hazards of working with compressed air, all safety precautions should be followed closely.

Small leaks or breaks in the compressed air system can cause minute particles to be blown at extremely high speeds. Always wear safety glasses when working in the vicinity of any compressed air system. Safety goggles are recommended if contact lenses are worn.

Compressors can make an exceptional amount of noise while running. The noise of the compressor, in addition to the drain valves lifting, creates enough noise to require hearing protection. The area around compressors should normally be posted as a hearing protection zone.

Pressurized air can do the same type of damage as pressurized water. Treat all operations on compressed air systems with the same care taken on liquid systems. Closed valves should be slowly cracked open, and both sides should be allowed to equalize prior to opening the valve further. Systems being opened for maintenance should always be depressurized before work begins.

f. Discuss the hazards associated with portable gases such as cylinders of oxygen, nitrogen, etc.

The following is taken from DOE-HDBK-1015/2-93.

Compressed and liquefied gases are widely useful due to properties including high heat output in combustion for some gases, high reactivity in chemical processing with other gases, extremely low temperatures available from some gases, and the economy of handling them all in compact form at high pressure or low temperature. These same properties, however, also represent hazards if the gases are not handled with full knowledge and care.

Practically all gases can act as simple asphyxiants by displacing the oxygen in air. The chief precaution taken against this potential hazard is adequate ventilation of all enclosed areas in which unsafe concentrations may build up. A second precaution is to avoid entering unventilated areas that might contain high concentrations of gas without first putting on breathing apparatus with a self-contained or hose-line air supply. A number of gases have characteristic odors that can warn of their presence in air. Others, however, like the atmospheric gases, have no odor or color. Warning labels are required for compressed and liquefied gas shipping containers. Similar warning signs are placed at the approaches to areas in which the gases are regularly stored and used.

Some gases can also have a toxic effect on the human system, either by inhalation, through high vapor concentrations, or by liquefied gas coming in contact with the skin or the eyes. Adequate ventilation of enclosed areas serves as the chief precaution against high concentrations of gas.

In addition, for unusually toxic gases, automatic devices can be purchased or built to monitor the gas concentration constantly and set off alarms if the concentration approaches a danger point. Precautions against skin or eye contact with liquefied gases that are toxic or very cold, or both, include thorough knowledge and training for all personnel handling such gases, the development of proper procedures and equipment for handling them, and special protective clothing and equipment (for example, protective garments, gloves, and face shields).

With flammable gases, it is necessary to guard against the possibility of fire or explosion. Ventilation, in addition to safe procedures and equipment to detect possible leaks, represents a primary precaution against these hazards. If fire breaks out, suitable fire extinguishing apparatus and preparation will limit damage. Care must also be taken to keep any flammable gas from reaching any source of ignition or heat (such as sparking electrical equipment, sparks struck by ordinary tools, boiler rooms, or open flames).

Oxygen poses a combustible hazard of a special kind. Although oxygen does not ignite, it lowers the ignition point of flammable substances and greatly accelerates combustion. It should not be allowed closer than 10 feet to any flammable substance, including grease and oil, and should be stored no closer than 10 feet to cylinders or tanks containing flammable gases.

Proper storage and handling of containers avoids many possible incidents. Hazards resulting from the rupture of a cylinder or other vessel containing gas at high pressure are protected against by careful and secure handling of containers at all times. For example, cylinders should never be struck nor allowed to fall, because if the cylinder is charged to a high pressure and the cylinder valve is broken off, it could become a projectile. Cylinders should not be dragged or rolled across the floor; they should be moved by a hand truck. Also, when they are upright on a hand truck, floor, or vehicle, they should be chained securely to keep them from falling over.

Moreover, cylinders should not be heated to the point at which any part of their outside surface exceeds a temperature of 125 °F, and they should never be heated with a torch or other open flame. Similar precautions are taken with larger shipping and storage containers. Initial protection against the possibility of vessel rupture is provided by the demanding requirements and recommendations for compressed gas container construction, testing, and retesting.

g. State the purpose of an air compressor unloader and discuss its basic operation.

According to DOE-HDBK-1016/1-93, an air compressor unloader is in place to operate in conjunction with the regulator to reduce or eliminate the load put on the prime mover when starting the unit. It is a valve that opens during starting to help minimize the load on the prime mover during startup to minimize wear. As the prime mover reaches operating speed, the valve shuts to allow the load to be added to the compressor.

h. Compare and contrast the principle of operation for centrifugal and reciprocating compressors.

Centrifugal Compressor

The following is taken from National Aeronautics and Space Administration, “Centrifugal Compressor.”

How does a centrifugal compressor work? The details are quite complex because the blade geometries and the resulting flows are three dimensional, unsteady, and can have important viscous and compressibility effects. Each blade on the compressor produces a pressure variation much like the airfoil of a spinning propeller. But unlike a propeller blade, the blades of a centrifugal compressor are close to one another, which seriously alters the flow between the blades. Centrifugal compressors also do work on the flow by turning, and therefore accelerating, the flow radially. Compressor designers must rely on wind tunnel testing and sophisticated computational models to determine the performance of a centrifugal compressor. The performance is characterized by the pressure ratio across the compressor CPR, the rotational speed of the shaft necessary to produce the pressure increase, and an efficiency factor that indicates how much additional work is required relative to an ideal compressor.

Reciprocating Compressor

The following is taken from Wikipedia, “Reciprocating Compressor.”

A reciprocating compressor or piston compressor is a positive-displacement compressor that uses pistons driven by a crankshaft to deliver gases at high pressure.

The intake gas enters the suction manifold, then flows into the compression cylinder where it gets compressed by a piston driven in a reciprocating motion via a crankshaft, and is then discharged. Applications include oil refineries, gas pipelines, chemical plants, natural gas processing plants and refrigeration plants.

18. Mechanical systems personnel shall demonstrate a working level knowledge of the basic design, construction, and operation of glovebox systems.

a. Explain the general functions of a glovebox and when glovebox use is appropriate.

The following is taken from Wikipedia, “Glovebox.”

A glovebox is a sealed container that is designed to allow one to manipulate objects where a separate atmosphere is desired. Built into the sides of the glovebox are gloves arranged in such a way that the user can place their hands into the gloves and perform tasks inside the box without breaking containment. Part or all of the box is usually transparent to allow the user to see what is being manipulated. Two types of gloveboxes exist: one allows a person to work with hazardous substances, such as radioactive materials or infectious disease agents; the other allows manipulation of substances that must be contained within a very high purity inert atmosphere, such as argon or nitrogen. It is also possible to use a glovebox for manipulation of items in a vacuum chamber.

b. Describe the design considerations of a glovebox, including shielding, criticality safety, seismic requirements, decontamination and decommissioning, materials, reinforcement, gloves and gloveports, filters, atmosphere, instrumentation, and testing.

The following is taken from DOE-HDBK-1169-2003.

Design Considerations

The principles of glovebox confinement are basic. Airflow of 125 ± 25 feet per minute (fpm) will maintain confinement through a breached gloveport. This is an inherent safety feature that should be incorporated into the glovebox system. Most nuclear, biological, and pharmaceutical facilities in the United States are designed to provide this capability. It is important to understand how this is achieved.

A glovebox is basically a closed volume. When the blower unit draws air (negative side) from the box, the box is under negative pressure. The filters help regulate this pressure. Filters are essentially controlled leaks that allow airflow through them while trapping the particulates they are designed to filter out. The inlet filter establishes the actual glovebox working pressure, while the exhaust filter system establishes the inherent safety feature. It is therefore critical for the exhaust filter to be properly engineered into the system to perform its inherent duty. When a gloveport breach occurs, by design the inlet filter is bypassed and the breached gloveport becomes the inlet.

The air change rate is an important consideration for all gloveboxes. As glovebox volume increases, airflow should increase. Nonetheless, the inherent safety feature of 125 ± 25 fpm through a gloveport must be maintained. For normal operations, flow rate is based on the dilution of evolved combustible or corrosive gases and heat dissipation, as well as prior experience. The exhaust capability must be sufficient to provide safety under postulated abnormal conditions, including the gloveport breach. In certain other applications, the exhaust capability must be sufficient to provide safe access for planned activities.

Operating personnel, industrial hygienists, and radiation specialists can assist the designer in establishing realistic requirements, particularly when an existing system is being replaced or revised. The types and quantities of materials to be used inside the box and their toxicity and

state (wet slurry, dry powder, etc.) must be considered when establishing the air exchange rate and velocity. When exposed radioactive material is handled inside a glovebox, the box becomes the primary confinement. When handling nuclear and pyrophoric materials, consideration should be given to whether pressure inside the glovebox should be positive or negative. A positive-pressured glovebox provides a motive force for airborne contamination to leak from the box into the secondary confinement. Negative pressure inside the box is essential to maintain glovebox confinement when working with radioactive material. It is not usually acceptable to design a normal operating condition that allows a primary confinement area to be positive to the secondary confinement area. However, in a unique or unusual application where an inert environment is used to control fire and explosion, the box may be slightly positive or even neutral, and the facility becomes the primary confinement. This suggests the need for a secondary confinement and also flags the need for personal protective equipment and appropriate procedures to protect the worker. The designer must design for failure to predict the consequences of a glovebox failure. The designer also must consider test and acceptance criteria.

Materials

It is important to understand the construction materials used on the filters and filter housings for gloveboxes, particularly chemical processing gloveboxes. It should be clearly understood which chemicals and gases will be introduced into the airstream of the glovebox and where they will be processed if processing is required. If a bag-in/bag-out port is used, the bag material is subject to the same exposure to chemicals and gases as the rest of the ventilation. If the process performed in the glovebox changes or other materials are introduced into the glovebox system, the compatibility of the materials must be re-evaluated. Simply put, the materials, ducting, blower unit, etc., must be compatible with the chemicals and gases exposed to the exhaust airstream.

Filters are available in many different materials for different purposes. Wood, several different stainless steel and aluminum materials, etc., are commonly selected for different applications. Recently developed technologies such as stainless steel, ceramic, and Teflon® filter media have outstanding resistance to chemicals, heat, and gases. However, these recent developments have not gained wide acceptance in nuclear applications.

Gloveports

The following is taken from “Modifications to Installed Sphincter Design Gloveports,” by S.S. Shetty and J.M. Gilkison, Westinghouse Savannah River Company.

Access to the interior of the gloveboxes is achieved through gloveports installed in the sides of the glovebox cabinets. These gloveports contain gloves that will accept the operator’s hands and arms. A mechanical seal is maintained between the glove and the gloveport to confine materials inside the gloveboxes. The confinement aspects of the gloveport seal are augmented by a differential pressure between the interior and the exterior. The pressure within the glovebox is negative to the exterior so air leakage past the gloveport seals is toward the interior of the glovebox.

Filters

The types of filter housings selected for use on gloveboxes have always been application-specific. As many nuclear facilities function under different directives, filter housings have evolved to suit their respective applications. Early gloveboxes often had externally mounted

HEPA filters. Because of the potential for spreading contamination during filter changes, this practice should be avoided.

Internal filter installations vary in design, however, and all have a mechanism to restrain the filter (a HEPA filter) and a sealing mechanism. These mechanisms also vary; however, it is critical that the mechanism be free of sharp edges that can easily cut gloves. Cracks and crevices should be kept to a minimum since the location makes cleaning difficult. Filter housing construction typically requires clean, smooth finishes to allow cleanup of contaminated or potentially contaminated areas. Experience has shown that areas exposed to contamination can be impossible to clean. The rougher the surface of the housing, the more difficult it is to clean. Valves, located to the outside, are used to isolate the spent filters during filter changes. Most applications use a prefilter to protect the HEPA filter, as well as a fire screen when there is a potential for fire. Although diverse, the many prefilter and fire screen designs should meet the requirements imposed in DOE-STD-1066-99.

The last basic requirement is a means and method to remove the contaminated filter from the glovebox. The most common method is the bag-in/bag-out method. Push-through filter housings differ in that they hold the standby filter in the filter housing. The filter is a cartridge type with chevron seals located at the inlet and the exhaust of the round cartridge filter. One of its advantages is that it is designed to maintain confinement during a filter change. A new filter displaces the spent filter as it is pushed through. The old filter and spacer are displaced to the inside of the glovebox. The inner pipe “tube” of the housing is honed to obtain a smooth, round surface. The chevron seal, which is larger than the internal diameter of the tube, creates the seal. Although this system has been used with great success, seal quality and tube finish are critical to its proper operation. This filter housing design is vulnerable, however, when it is used for applications involving light, easily airborne materials. Such materials, if surface-deposited on the inside tube, can bypass the seals during a filter change because the seal can “roll over” the material. Another potential drawback of this design is its orientation. It should be installed in a vertical position for proper sealing. A horizontal installation will enable the seals to “take a set” and eventually bypass the filter. This filter housing has been used at nuclear facilities in the United States for many years with good reliability; however, its limitations should be noted.

Cartridge filters can be used for glovebox operations for both radioactive and nonradioactive applications. These filters incorporate the filter housing and filter as a single unit and are supplied from the manufacturer with options for pipe nipple connections on both the inlet and exhaust or on one end only. Test ports should be specified when ordering, as these filters range in size and airflows. Prefilters should be installed inside the glovebox for filters not already equipped with prefilters. A valve should be located on the outside of the glovebox filter housing.

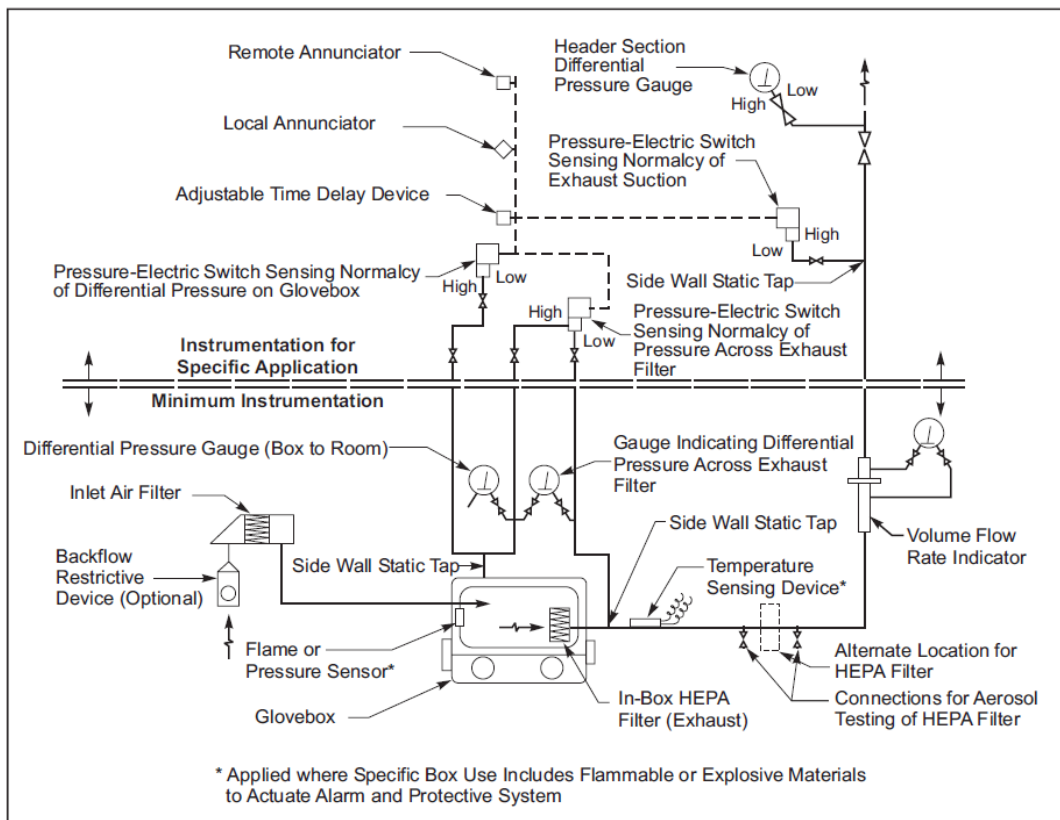
Instrumentation

Glovebox instrumentation may range from simple indicators and alarms to sophisticated control systems. The type of control or instrument used will depend on the characteristics to be monitored, the relative hazards, and the method and time available to correct an upset condition. Operational characteristics to be measured and alarmed should always include the differential pressure between box and surroundings, the filter resistance, the gas flow rate through the box, and the box atmospheric temperature. An alarm should be available for any activity that could lead to degradation of or loss of confinement, fire, or any other safety concerns. In addition to

instruments and sensors on the box, it may be necessary to indicate and provide for readouts and/or alarms at a central panel for oxygen content, liquid level, neutron flux, gamma flux, fire, and explosive gas mixture inside the box.

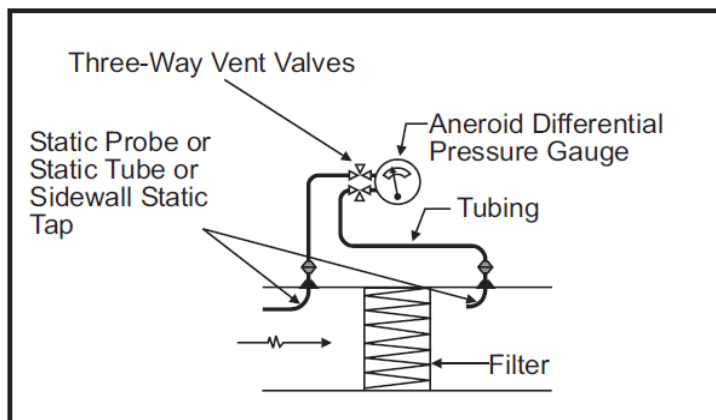
When a monitored characteristic requires annunciation for safety in case the level of a monitored parameter passes some predetermined point, the alarm may be local. For example, an alarm may alert the operator to an upset condition (e.g., when the glovebox pressure differential becomes less negative than its design relative to the surroundings) or it may signal an annunciator panel in an adjoining “cold” area (e.g., by the entry door to the glovebox room, in a control room, or both). Standard operating procedures and sufficient information on the current contents of each box should be available to assist evaluation of the hazard area when an alarm sounds and to aid in planning corrective action.

Minimum instrumentation for a glovebox ventilation system should include devices to indicate the differential pressure between the box and its surroundings, exhaust filter resistance, total exhaust flow rate, and exhaust air temperature. Figure 68 shows the arrangement of indicating devices in a glovebox ventilation system. The items shown above the double-dashed line indicate the types of instruments commonly used to supplement the minimum instrumentation necessary to improve safety for a particular operation or circumstance. For example, when box operators are not in full-time attendance for a continuous process, a sensor can be provided to monitor abnormal pressure, temperature, or almost any other critical process parameter and to actuate a remote alarm where an attendant is stationed.



Source: DOE-HDBK-1169-2003

Figure 68. Arrangement of indicating devices



Source: DOE-HDBK-1169-2003

Figure 69. Typical local mounting for a differential pressure gauge

glovebox as possible to prevent contamination migration into the gauge lines and gauge. Tubing should be at least 3/16 inch diameter to allow the instrument to respond quickly to rapid changes in pressure. Use of a three-way vent valve at the gauge permits easy calibration (zeroing) without disconnecting the sensing tube. Calibration of glovebox differential pressure gauges should be done routinely.

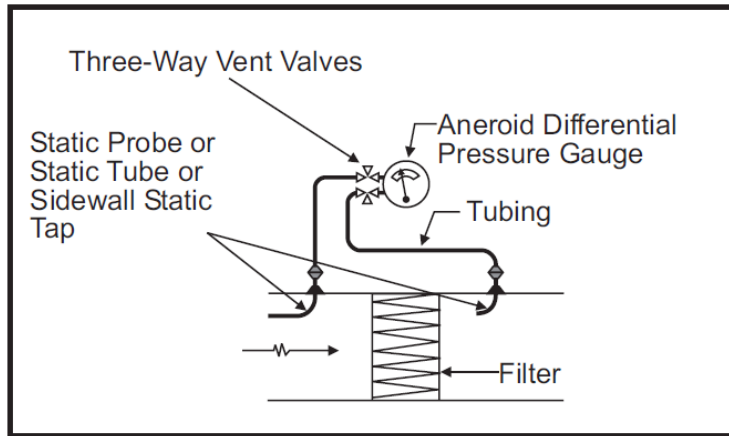
Selection of a differential pressure gauge, differential pressure gauge with switch, or transducer should be determined by the application. One advantage of using a gauge is simplicity. A line is connected across the upstream and downstream plenums of a filter where the pressure drop can be measured. Most gauges and transducers install in this manner. A differential pressure gauge with switch has the addition of an alarm function. A transducer allows multiple readouts and greater accuracy, and can be used to automate the exhaust system. It is more costly, however, because it must have a power supply, readout, and transducer.

The requirement for a gauge should be based on the actual system pressure. Exhaust filter pressure drops, for example, can vary up to 3 in.wg. If the inlet filter housing valve is closed, the device will see the full negative capacity of the blower. The gauge or transducer must have a proof pressure greater than the maximum system pressure (negative or positive) so that it will not be damaged by excessive pressure.

Devices that measure pressure have a problem with “drift.” This occurs on most devices because of continual pressure on the device. As a result, they must be recalibrated on a routine schedule. Liquid-filled devices (manometers) are not recommended for glovebox pressure indicators; however, they have been used to check the calibration of an existing device. Inlet filters on air-ventilated gloveboxes generally do not require differential pressure gauges. The pressure drop across the inlet filter is approximately the same as the box pressure. A differential pressure gauge should be provided for each exhaust HEPA filter stage to indicate filter resistance. Pressure-sensing connections can be provided to permit the use of portable instruments. Suitable alarms or controls that can function on small pressure differentials (equal to 0.25 in.wg) are difficult to keep calibrated and are often expensive.

Figure 69 shows an example of a local mounting for a differential pressure gauge on top of a glovebox. The instrument should be mounted near eye level, and the indicating face should be located so that the operator has a clear view while manipulating the gloves. The gauge display should make operating conditions easily discernible to the operator. Sensing lines should be short and should be

sloped directly back to the glovebox so that moisture will not pocket in the tube. Inline HEPA filters should be located either inside or as close to the



Source: DOE-HDBK-1169-2003

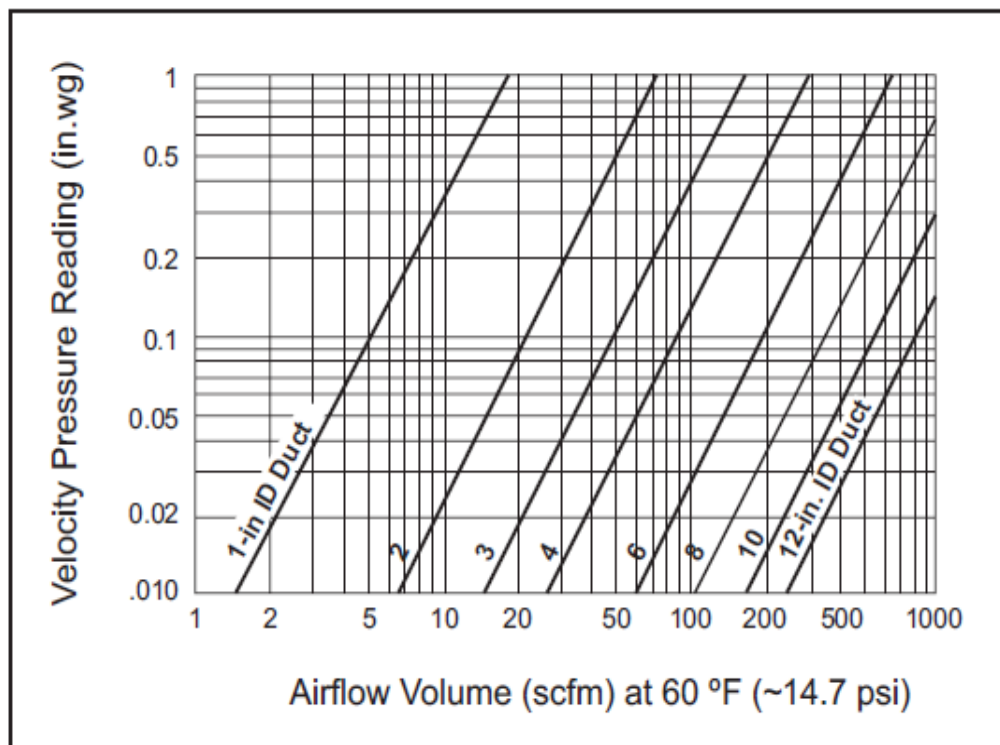
Figure 70. Indicating a pressure drop through a filter

glovebox ventilation. VP measurements (corrected for pitot-tube single centerline location) for airflows and duct sizes common in glovebox applications are given in figure 71.

Figure 70 shows a method for indicating pressure drop through a filter.

Instruments used to measure airflow rates from gloveboxes include an orifice plate, venturi meter, flow nozzle, and calibrated pitot tube. The important point is to use a simple, trouble-free device that gives reliable readings within an accuracy of ± 15 percent. When free moisture is absent,

a pitot tube is the least expensive and most adaptable device for the small volume flow rates associated with



Source: DOE-HDBK-1169-2003

Figure 71. Velocity measurements

The corrections shown are for air at 60 °F and 14.7 psia, and neglect the pitot tube coefficient. Pitot tubes are available with coefficients of 1.00, but there is an advantage in using the more common commercial pitot tube with a coefficient of 0.825 at low flow velocities.

The equation for measuring velocity with a pitot tube is shown below:

$$V = K(2gh)^{1/2}$$

where

V = fluid velocity (ft/sec)

K = coefficient of the pitot tube

g = acceleration of gravity (32.17 ft/sec²)

h = velocity pressure (ft) of the air-gas stream.

The following equation is used for air at standard conditions:

$$V = 4005 K(hw)^{1/2}$$

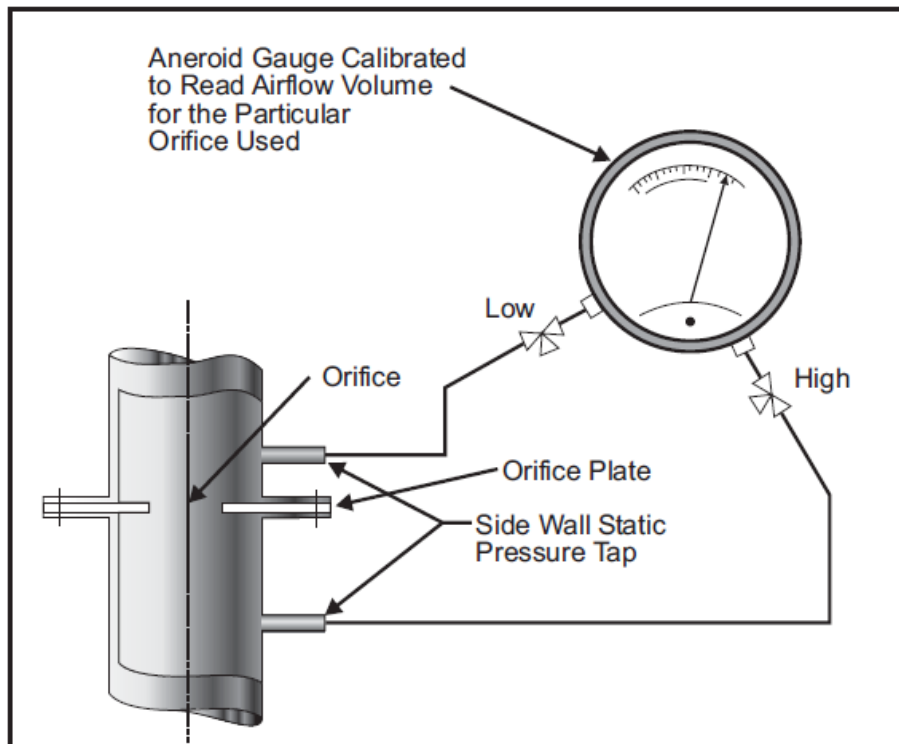
where

V = fluid velocity (fpm)

hw = velocity pressure (in.wg).

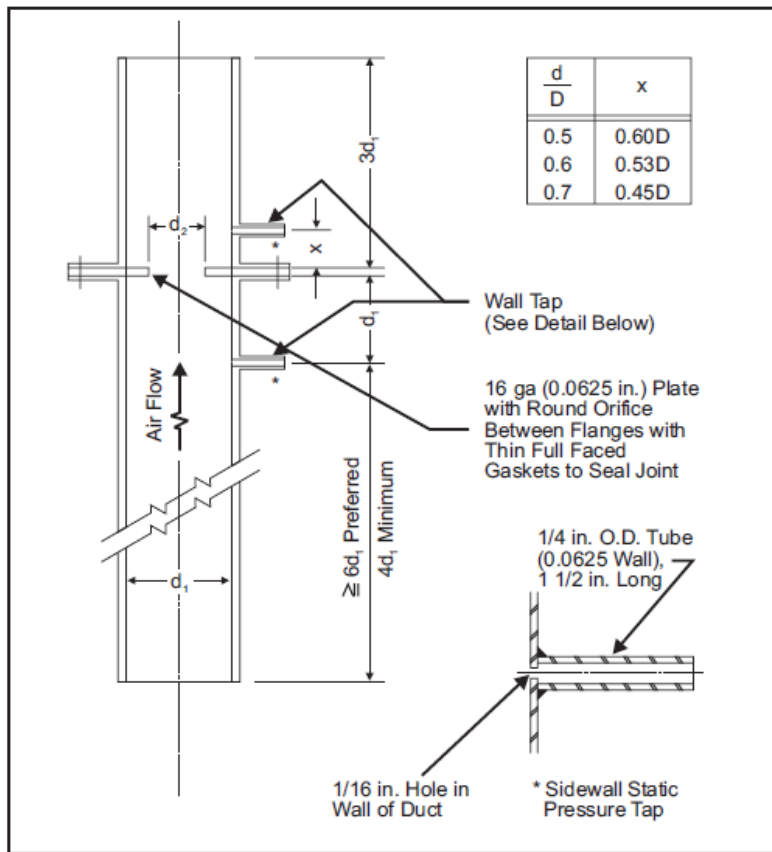
A pitot tube with a coefficient of 0.825 has a velocity pressure reading that is 1.47 times the velocity pressure reading of the pitot tube with a coefficient of 1.00 for the same fluid velocity. This pressure differential allows the low velocities often encountered in glovebox ventilation to be measured more easily.

Figure 72 shows the arrangement of a round orifice in a straight section of metal duct.



Source: DOE-HDBK-1169-2003

Figure 72. Orifice meter method of measuring volume flow rate in small ducts



Source: DOE-HDBK-1169-2003

Figure 73. Arrangement of sharp-edge concentric orifice in small duct

Either method (pitot tube or orifice) can be used to read the flow volume directly on a properly calibrated gauge. For a thin, sharp-edged, round, concentric orifice with the properties given in figure 73, the flow rate can be determined with sufficient accuracy for glovebox applications by the following equation:

$$Q = 14d^2h^{1/2}$$

where

Q = airflow (cfm)

d = orifice diameter (in.)

h = pressure drop across orifice (in.wg).

Assumptions inherent in the constant 14 used in the above equation include (1) air at standard temperature and pressure, (2) flow coefficient for orifice = 0.65, and (3) ratio of orifice diameter to smooth-duct diameter, D , $0.2 = d/D = 0.7$.

The practical use of this formula can be shown by the following example:

Determine the orifice size necessary for a 20 cfm airflow rate that would give a reading near the center of scale on a 0 to 0.50-inch-range gauge.

$$Q = 20 \text{ cfm}$$

$$h = \frac{0.50}{2} = 0.25 \text{ in.wg}$$

$$d = \frac{Q}{14h^{1/2}} = \frac{20}{14(0.25)^{1/2}}$$

$$D = 1.79 \text{ in.}$$

For 3-inch schedule 10 stainless steel pipe (3.260-inch diameter), the d/D ratio is $1.79/3.26 = 0.55$, which is within the acceptable range.

A shortcoming of the thin-plate orifice is loss of head of the air flowing through the device. Table 1 gives the loss of head of concentric orifices for various d/D ratios.

Table 1. Loss of head for various d/D ratios

d/D ratios	Fractions of velocity head not regained
0.2	0.95
0.3	0.89
0.4	0.83
0.5	0.74
0.7	0.53

Source: DOE-HDBK-1169-2003

In the example above, $0.70 \times 0.20 = 0.14$ in.wg is the pressure loss when 20 cfm flows through the orifice of $d/D = 0.55$.

Immediately after installation and while filters are still clean, the measured pressure drop across the HEPA filter can be used to check airflow to a high degree of accuracy by proportioning the measured pressure drop to that stamped on the filter case at the time of predelivery testing. The pressure drop across the filter is no longer a dependable indication of gas flow rate after the filter has accumulated dust. After a filter has been in service for a period of time, it is necessary to measure both the pressure drop across the filter and the airflow through it to evaluate the filter's status and relationship to the whole ventilation system.

Shielding

Some gloveboxes may require gamma, beta, and neutron shielding because of the nuclides used and the amounts of material involved. Boxes handling kilogram quantities of plutonium can be shielded by providing lead-impregnated gloves, glovebox shielding (water or any other similar mass), lead glass over the windows, and lead-hinged plugs or covers over the ports. The operating, shielding, removal, and replacement requirements of the glovebox HEPA filter must also be considered when glovebox shielding is required. The thickness of the shielding affects the design of the filter housing used on a shielded glovebox. The designer should account for this by extending the service fittings (pressure measurement) and any other glovebox pass-through used in the design. This practice is also mandated for bagging ports used to remove the primary HEPA filters and the cover doors. Ergonomic operations inside shielded gloveboxes should be given careful consideration because lead-lined gloves and dimensional differences make manipulations very difficult.

Seismic Considerations

By their very nature, gloveboxes are typically top heavy. This presents some unique challenges when designing the supports and hold-downs for the systems during a postulated seismic event. Several facilities have had to redesign their support systems after the facility was operating. This led to many obstructions and interferences that could have been avoided at an earlier design stage.

Criticality Considerations

When criticality is a potential concern for glovebox design, care must be taken in providing for the appropriate geometry control and water use restrictions. Drains, in particular, must be

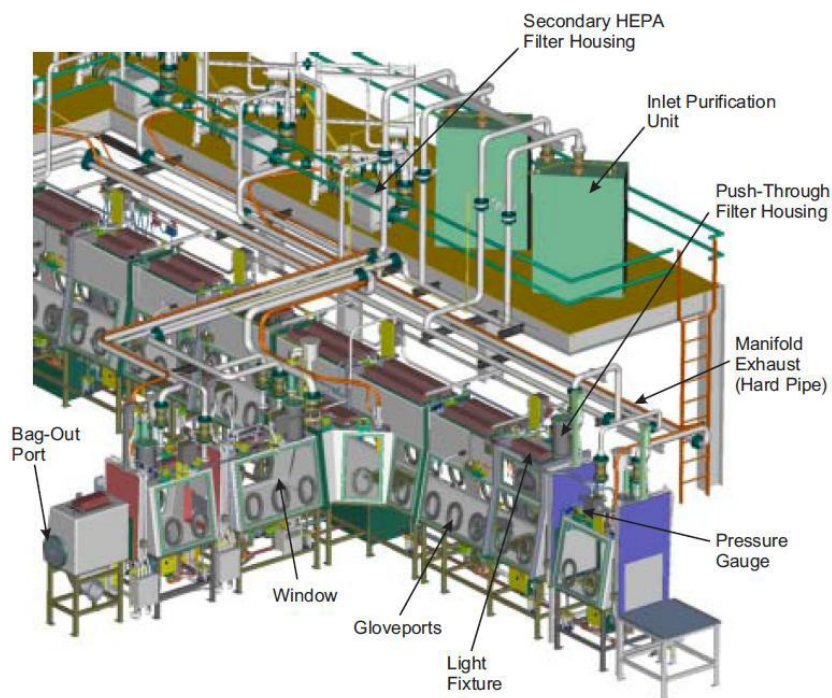
designed with great care. The buildup of fissile material on the HEPA filters must also be considered.

c. Describe the operation of gloveboxes.

The following is taken from DOE HDBK-1169-2003.

Gloveboxes are enclosures that enable operators in various industries (e.g., nuclear, biological, pharmaceutical, microelectronics) to use their hands to manipulate hazardous materials through gloves without exposure to themselves or subsequent unfiltered release of the material to the environment. In the nuclear industry, gloveboxes provide primary confinement for radioactive material handling and process protection and are used to handle a diverse range of chemical, oxygen-sensitive, pyrophoric, hazardous, and nuclear materials. (Note: There are many other factors, [e.g., seismic, shielding, etc.] that could impact glovebox filtration design and operation. Secondary confinement may be provided by the room or building where the gloveboxes are located.)

Ventilation is the heart of the glovebox system. Nuclear materials requiring handling inside a glovebox usually present little or no penetrating radiation hazard, but emit radioactive particles that could be dangerous if inhaled. Gloveboxes prevent operators from inhaling radioactive particles as they work with various nuclear materials and help provide a clean, controlled, safe working environment. For glovebox ventilation to be effective, however, proper design pressures and flow criteria must be maintained. Glovebox pressures range from mostly negative (for confinement) to positive pressure environments (for process protection). Failure to maintain correct operational pressures or to follow established operational procedures could render a glovebox both ineffective and unsafe.



Source DOE-HDBK-1169-2003

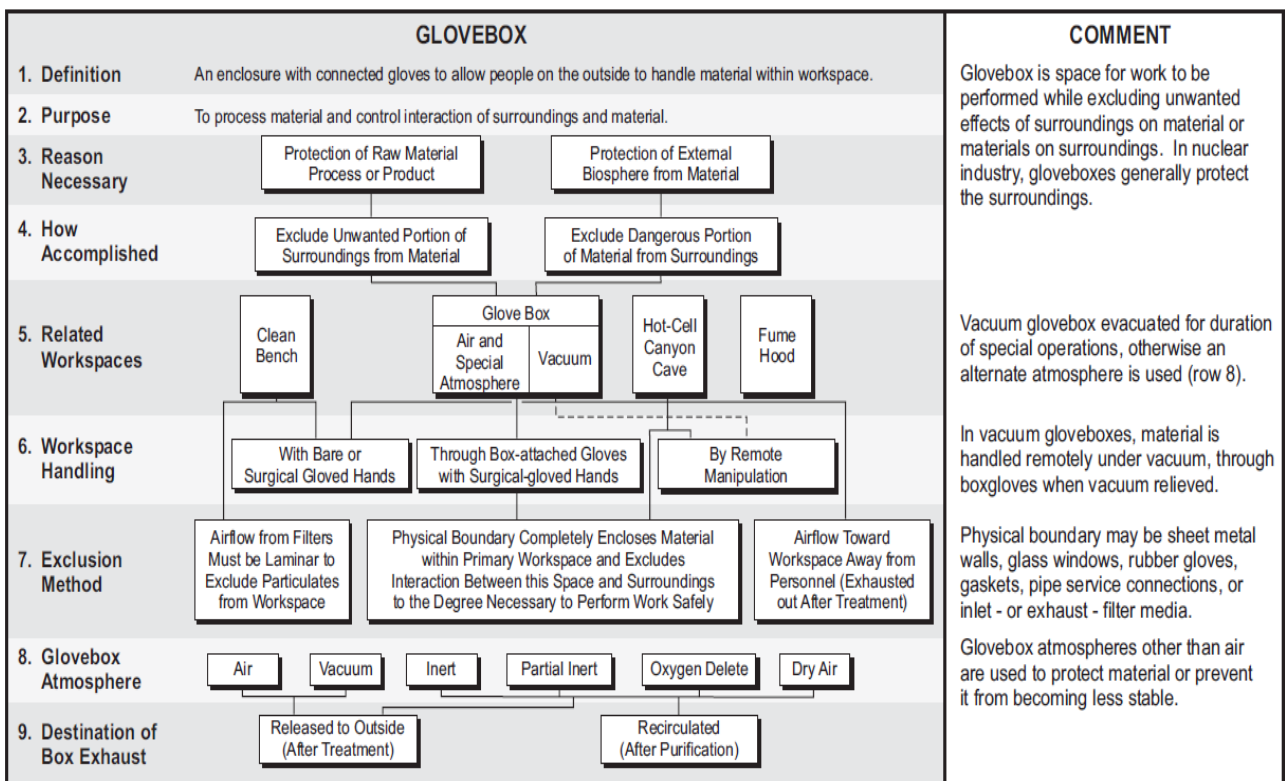
Figure 74. Typical glovebox with major features

A glovebox (figure 74) is a windowed, airtight (sometimes gas-tight) enclosure that may be capable of positive or negative internal pressure. It is equipped with one or more flexible gloves for manipulation of materials and performance of operations inside the enclosure from the outside, uncontaminated environment.

Figure 75 defines and lists characteristics of gloveboxes, with a focus on their use in the nuclear industry.

Originally, many gloveboxes were vendor-designed, so the designs were proprietary. As a result, many older boxes have unique ventilation designs. Today, professional societies such as the American Glovebox Society (AGS) have documentation such as AGS-G001-1998, *Guidelines for Gloveboxes*, which was written by Government employees and vendors who work with, manufacture, and design gloveboxes. This document contains useful information on subjects ranging from the need for a glovebox to related QA acceptance programs.

There are still manufacturers who produce “research-type” gloveboxes in the United States today. These boxes can be used by some DOE facilities, but it is not advisable to use them for nuclear activities, as most are not equipped with a method for safely changing the HEPA filters.



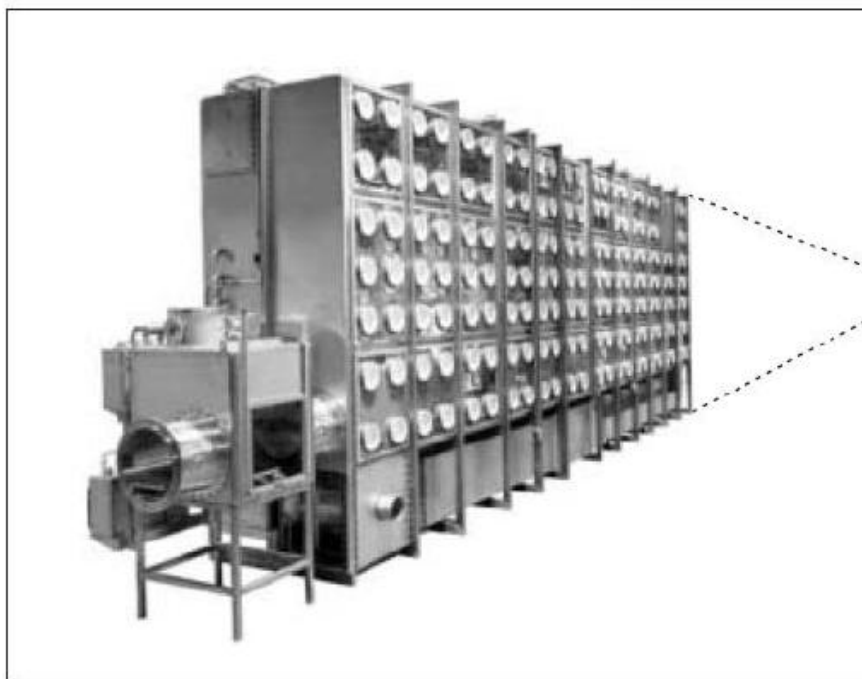
Source: DOE-HDBK-1169-2003

Figure 75. Glovebox characteristics

Ongoing development of gloveboxes for use by the nuclear industry has resulted in many changes through the years. Gloveboxes have evolved from the somewhat standard sizes to larger custom systems containing all of the process-related equipment. The larger gloveboxes

have some unique characteristics. Some are as large as 150 feet long, 4 feet deep, and 15 feet tall.

See figure 76 for a portion of this type of glovebox. Note the numerous gloveports, which allow access to all points in the box. Their ventilation design includes side-access filter housings. Other design philosophies place drive motors, equipment, and electrical devices externally, thereby reducing maintenance, heat loading, size, and disposal costs. Seals are used to pass drives and electrical controls through the glovebox pressure boundary. In some cases, the design philosophy has been to size the glovebox for a specific process to minimize volume and service requirements. In all cases, ergonomics and confinement are critical to the performance of daily operations and routine maintenance.



Source: DOE-HDBK-1169-2003

Figure 76. Glovebox with multiple gloveports to facilitate access

Gloveboxes generally have several common characteristics. They are often no deeper than 26 inches (as far as most arms can reach—it is desirable to be able to reach most areas of a glovebox). If deeper space is needed, a dual side-access design may be selected. These contain one or more safety glass, laminated-glass, or polymer viewing windows located on at least one side. Gloveports (window-mounted or in the stainless steel shell) are usually available in multiples of two at various locations in the

glovebox walls. Interior workspace is reserved for primary operating purposes on the box floor between the gloveports and within reach of a gloved hand. Remote handling capabilities, other than tool extensions for the gloved hand, are usually not provided.

Gloveboxes are normally kept at a negative pressure of 0.3 to 0.5 in.wg relative to their surroundings. The maximum safe operating differential pressure between the interior and exterior of the box is usually less than 4 in.wg; greater differential pressure may damage or rupture a glove or window, causing subsequent loss of confinement. Operators experience fatigue when pressures inside a glovebox are greater than 0.5 in.wg, and performance of intricate tasks becomes tedious. Material and HEPA filter transfers between glovebox interiors and exteriors are commonly made through a bagging port, which, although time consuming and user-dependent, is still the safest practical way of maintaining confinement.

New versions of this technology use a banding system. Other material transfers use rapid transfer ports (RTPs), which allow simple docking from glovebox to glovebox. This is a reliable

method of maintaining confinement as long as the seals are maintained and undamaged. (Note: Transfers of powders can egress past the seals if exposed. Such powders should be contained in a secondary container and the seals protected during operations.)

Gloveboxes with RTPs are still equipped with bagging ports for filter changes and waste disposal.

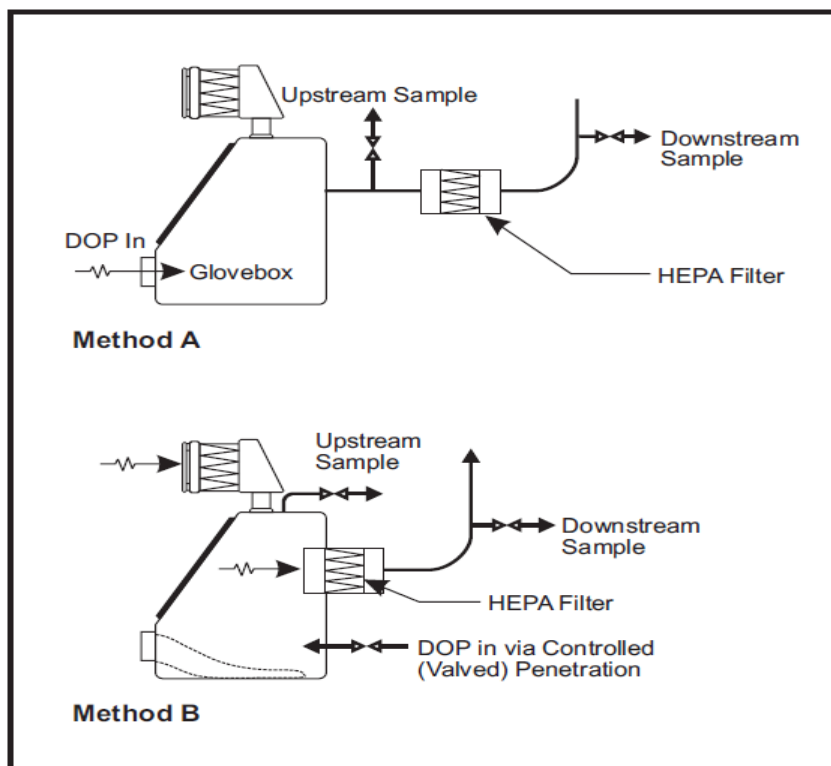
HEPA filter installations must adapt to limitations while still providing reliable service. Hybrid glovebox shielded cells, vacuum gloveboxes, room-high gloveboxes, glovebox “trains,” etc., are often encountered, and all require reliable filter installations. Special atmospheres such as inert gas and dry air are often used in gloveboxes for fire suppression and for oxygen-sensitive and/or moisture-sensitive materials and processes. Gas purification systems are commonly used in conjunction with inert environments to maintain environmental control. These units purify and dry the environment to prevent consumption of large volumes of inert gas and desiccant. It is important to protect these devices from contamination because they constantly recirculate the volumes of the gloveboxes they serve.

Video 46. Glovebox

<http://www.bing.com/videos/search?q=glovebox&view=detail&mid=8D6A9CBB5AE2C6A71BF88D6A9CBB5AE2C6A71BF8&first=41>

d. Describe the maintenance, including routine surveillances that may be applicable to gloveboxes.

The following is taken from DOE-HDBK-1169-2003.



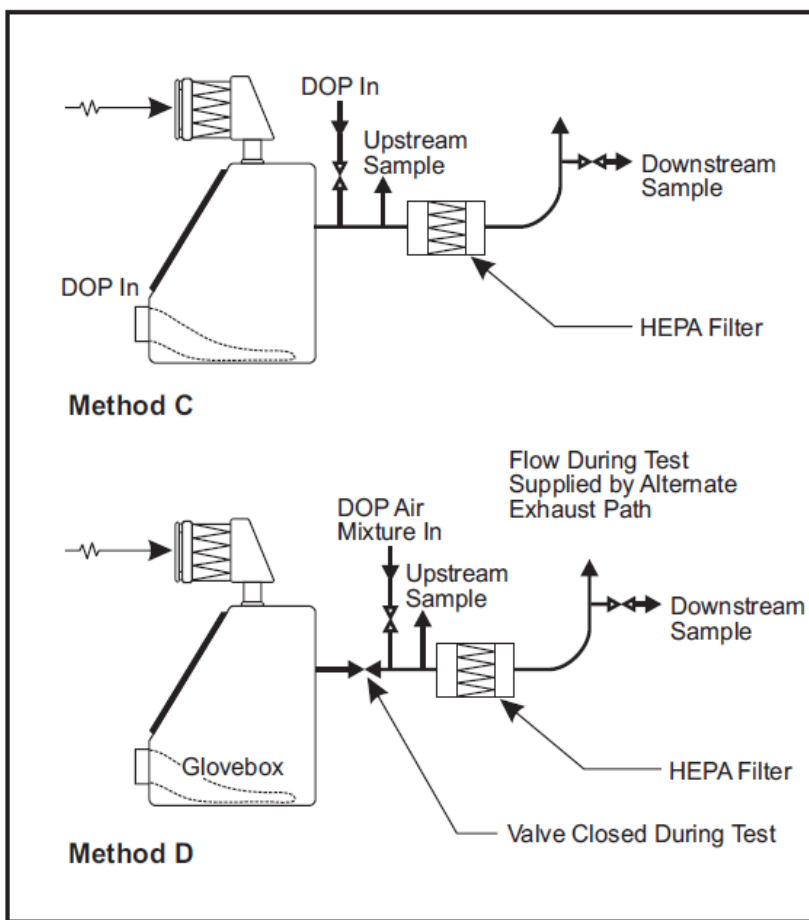
Source: DOE-HDBK-1169-2003

Figure 77. Methods of injecting test aerosol and extracting samples (Methods A and B)

The size of a glovebox filter housing is relatively small compared to most filter housing installations. As with any HEPA filter installation, test ports should be placed on the filter housing to validate the installation. The criteria for testing gloveboxes focus on the proper location to inject the challenge aerosol, upstream, and downstream samples. The test ports should be designed to be sealed after each use and to be as cleanable as possible. This is usually a $\frac{3}{8}$ - to $\frac{1}{2}$ -inch half-coupling/nipple with the appropriate plug/cap. The weld and finish of a test port should emphasize clean smooth surfaces, especially from the

inner diameter of the port to the filter housing. Cracks and crevices in this area are next to impossible to clean via access through gloveports.

Testable HEPA filter installations must be tested immediately after installation and then again periodically to ensure that air cleanup capability and confinement integrity remain intact. The HEPA filters used in glovebox systems are often inconvenient to test because the challenge aerosol must be injected into the inlet duct or glovebox. The challenge aerosol cannot be fed into the inlet of the box to test the exhaust-side filters if high-efficiency filters are used in the inlet. Methods A and B (figure 77) require the challenge aerosol to be drawn into the glovebox by the suction of the exhaust system. However, the challenge aerosol should not be injected into gloveboxes that house apparatus with open or exposed optical lenses or with highly polished surfaces, delicate balances, crystalline structures, sensitive conductors, or similar equipment or products. In such cases, the filter should be installed in the duct downstream of the glovebox so that the injected challenge aerosol will not back up into the glovebox proper. Method C (figure 78) may then be used for challenge aerosol testing of the exhaust HEPA filter. Where new or replacement exhaust filters are required to be tested before restarting the ventilation system, method D (figure 78) may be used. Note that in this method the exhaust path from the glovebox is closed, and the challenge aerosol-air mixture for filter testing is drawn from a separate valved path. The side path is closed and sealed after testing is completed. Methods A and B (figure 77) require injection of the challenge aerosol-air mixtures into the glovebox via some convenient opening. A gloveport can be used if confinement is not critical during testing. Otherwise, a connection can be prepared (figure 78), or an alternate method can be devised. Methods C and D (figure 78) do not require the introduction of a challenge aerosol into the glovebox. The challenge aerosol inlet connection must be sized to pass the challenge aerosol or challenge aerosol-air mixture.



Source: DOE-HDBK-1169-2003

Figure 78. Methods of injecting aerosols and extracting samples (Methods C and D)

The connection for concentrated challenge aerosol in method C must admit 2 to 5 cfm, while the connection in method D must accommodate the total challenge aerosol-air mixture used for the test.

19. Mechanical systems personnel shall demonstrate a working level knowledge of the principles of lubrication.

a. Define the following terms as related to lubricants:

- **Viscosity**
- **National Lubricating Grease Institute grease grades**

Viscosity

The following is taken from the New World Encyclopedia, “Viscosity.”

Viscosity is a measure of the resistance of a fluid to deform under either shear stress or extensional stress. It is commonly perceived as thickness, or resistance to flow. Viscosity describes a fluid’s internal resistance to flow and may be thought of as a measure of fluid friction. Thus, water is thin, having a lower viscosity, while vegetable oil is thick, having a higher viscosity. All real fluids have some resistance to stress, but a fluid which has no resistance to shear stress is known as an ideal fluid or inviscid fluid. The study of viscosity is known as rheology.

In liquids, the additional forces between molecules become important. This leads to an additional contribution to the shear stress, though the exact mechanics of this are still controversial. Thus, in liquids

- viscosity is independent of pressure
- viscosity tends to fall as temperature increases

The dynamic viscosities of liquids are typically several orders of magnitude higher than the dynamic viscosities of gases.

Video 47. Viscosity

<http://www.bing.com/videos/search?q=viscosity&view=detail&mid=781FBF66731E91EA074C781FBF66731E91EA074C&first=21>

National Lubricating Grease Institute Grease Grades

The following is taken from Marine Engineering Knowledge, “National Lubricating Grease Institute Grease Grades.”

National Lubricating Grease Institute (NLGI) grade is a widely used classification for lubricating greases. It was established by the National Lubricating Grease Institute. Greases are classified in one of nine grades based on their consistency. NLGI grade alone is not sufficient for specifying the grease for a particular application but it is a useful qualitative measure. While the science of tribology is still developing, NLGI grade, in combination with other test-based properties, is the only method for determining the potential suitability of various greases for a specific application.

The nine grades are defined by a range of worked penetration test results. The NLGI grade for a specific grease is determined using two test apparatus. The first apparatus consists of a closed container and a piston-like plunger. The face of the plunger is perforated to allow grease to flow from one side of the plunger to another as the plunger is worked up and down. The test grease is

inserted into the container and the plunger is stroked 60 times while the test apparatus and grease are maintained at a temperature of 25°C.

Once worked, the grease is placed in a penetration test apparatus. This apparatus consists of a container, a specially configured cone, and a dial indicator. The container is filled with the grease and the top surface of the grease is smoothed over. The cone is placed so that its tip just touches the grease surface and a dial indicator is set to zero at this position. When the test starts, the weight of the cone will cause it to penetrate into the grease. After a specific time interval the depth of penetration is measured.

Table 2 shows the NLGI grades and the worked penetration ranges:

Table 2. NLGI Grade Worked penetration after 60 Strokes at 25 °C (0.1 mm)

Appearance	Consistency	Food Analog
000	445-475 fluid	Cooking oil
00	400-430 semi-fluid	Applesauce
0	355-385 very soft	Brown mustard
1	310-340 soft	Tomato paste
2	265-295 “normal” grease	Peanut butter
3	220-250 firm	Vegetable shortening
4	175-205 very firm	Frozen yogurt
5	130-160 hard	Smooth pate
6	85-115 very hard	Cheddar cheese

Source: Marine Engineering Knowledge, National Lubricating Grease Institute Grease Grades

b. Identify and discuss various types of lubricants and concerns regarding their potential corrosion of components and systems, including the following:

- Oil
- Water
- Solids/powders
- Gaseous
- Grease

The following is taken from Wikipedia, “Lubricant.”

A lubricant is a substance introduced to reduce friction between moving surfaces. It may also have the function of transporting foreign particles. The property of reducing friction is known as lubricity.

A good lubricant possesses the following characteristics:

- High boiling point
- Low freezing point
- High viscosity index
- Thermal stability
- Corrosion prevention
- High resistance to oxidation

One of the single largest applications for lubricants, in the form of motor oil, is protecting the internal combustion engines in motor vehicles and powered equipment.

Typically lubricants contain 90 percent base oil and less than 10 percent additives. Vegetable oils or synthetic liquids such as hydrogenated polyolefins, esters, silicones, fluorocarbons and many others are sometimes used as base oils. Additives deliver reduced friction and wear, increased viscosity, improved viscosity index, resistance to corrosion and oxidation, aging or contamination, etc.

Lubricants such as 2-cycle oil are added to fuels like gasoline, which has low lubricity. Sulfur impurities in fuels also provide some lubrication properties, which has to be taken in account when switching to a low-sulfur diesel; biodiesel is a popular diesel fuel additive providing additional lubricity.

Non-liquid lubricants include grease, powders (dry graphite, Polytetrafluoroethylene [PTFE], Molybdenum disulfide, tungsten disulfide, etc.), PTFE tape used in plumbing, air cushion and others. Dry lubricants such as graphite, molybdenum disulfide and tungsten disulfide also offer lubrication at temperatures (up to 350°C) higher than liquid and oil-based lubricants are able to operate. Limited interest has been shown in low friction properties of compacted oxide glaze layers formed at several hundred degrees Celsius in metallic sliding systems; however, practical use is still many years away due to their physically unstable nature.

Another approach to reducing friction and wear is to use bearings, such as ball bearings, roller bearings or air bearings, that in turn require internal lubrication themselves, or to use sound, in the case of acoustic lubrication.

Types of Lubricants

In 1999, an estimated 37,300,000 tons of lubricants were consumed worldwide. Automotive applications dominate, but other industrial, marine, and metal working applications are also big consumers of lubricants. Although air and other gas-based lubricants are known, liquid and solid lubricants dominate the market, especially the former.

Lubricants are generally composed of a majority of base oil plus a variety of additives to impart desirable characteristics. Although lubricants are generally composed of one type of base oil, mixtures of the base oils also are used to meet performance requirements.

Base Oil Groups

The term mineral oil is used to encompass lubricating base oils derived from crude oil. The API designates several types of lubricant base oil:

- Group I – Saturates <90% and/or sulfur >0.03%, and Society of Automotive Engineers (SAE) viscosity index (VI) of 80 to 120—Manufactured by solvent extraction, solvent or catalytic dewaxing, and hydro-finishing processes. Common Group I base oils are 150SN (solvent neutral), 500SN, and 150BS (brightstock)
- Group II – Saturates over 90% and sulfur under 0.03%, and SAE viscosity index of 80 to 120—Manufactured by hydrocracking and solvent or catalytic dewaxing processes. Group II base oil has superior anti-oxidation properties since virtually all hydrocarbon molecules are saturated. It has water-white color.
- Group III – Saturates > 90%, sulfur <0.03%, and SAE viscosity index over 120—Manufactured by special processes such as isohydromerization. Can be manufactured from base oil or slax wax from dewaxing process.

- Group IV – Polyalphaolefins (PAO) — Made by polymerizing an alphaolephin. Useful as synthetic lubricants such as synthetic motor oils for vehicles used in a wide temperature range since they remain viscous even at low temperatures.
- Group V – All others not included above such as naphthenics, polyalkylene glycol, esters. In North America, Groups III, IV and V are now described as synthetic lubricants, with group III frequently described as synthesised hydrocarbons, or SHCs. In Europe, only Groups IV and V may be classed as synthetics.

The lubricant industry commonly extends this group terminology to include

- Group I+ with a Viscosity Index of 103–108
- Group II+ with a Viscosity Index of 113–119
- Group III+ with a Viscosity Index of at least 140

Can also be classified into three categories depending on the prevailing compositions

1. paraffinic
2. naphthenic
3. aromatic

Lubricants for internal combustion engines contain additives to reduce oxidation and improve lubrication. The main constituent of such lubricant product is called the base oil, base stock. While it is advantageous to have a high-grade base oil in a lubricant, proper selection of the lubricant additives is equally as important. Thus some poorly selected formulation of PAO lubricant may not last as long as a more expensive formulation of Group III+ lubricant.

Biolubricants Made From Vegetable Oils and Other Renewable Sources

These are primarily triglyceride esters derived from plants and animals. For lubricant base oils, use of vegetable derived materials is preferred. Common ones include high oleic canola oil, castor oil, palm oil, sunflower seed oil, and rapeseed oil from vegetables, and tall oil from trees. Vegetable oils are often hydrolyzed to yield the acids which are subsequently combined selectively to form specialist synthetic esters. Other naturally derived lubricants include whale oil and lanolin.

Whale oil was a historically important lubricant, with some uses up to the latter part of the 20th century as a friction modifier additive for automatic transmission fluid.

Lanolin is a natural water repellent, derived from sheep wool grease, and is an alternative to the more common petro-chemical based lubricants. This lubricant is also a corrosion inhibitor, protecting against rust, salts, and acids.

Water can also be used on its own or as a major component in combination with one of the other base oils. It is commonly used in engineering processes, such as milling and lathe turning.

Solid Lubricants

PTFE is typically used as a coating layer on, for example, cooking utensils to provide a non-stick surface. Its usable temperature range up to 350°C and chemical inertness make it a useful additive in special greases. Under extreme pressures, PTFE powder or solid is of little value as it is soft and flows away from the area of contact. Ceramic or metal or alloy lubricants are a better choice under those circumstances.

Inorganic solids—Graphite, hexagonal boron nitride, molybdenum disulfide, and tungsten disulfide are examples of materials that can be used as solid lubricants, often to very high temperatures. The use of such materials is sometimes restricted by their poor resistance to oxidation.

Metal/alloy—Metal alloys, composites and pure metals can be used as grease additives or as the sole constituents of sliding surfaces and bearings. Cadmium and Gold are used for plating surfaces which gives them good corrosion resistance and sliding properties; lead, tin, zinc and various bronze alloys are used as sliding bearings, or their powder can be used alone to lubricate sliding surfaces, or as an additive to grease.

Aqueous lubrication—Aqueous lubrication is of interest in a number of technological applications. Strongly hydrated brush polymers such as polyethylene glycol can act as lubricants at liquid/solid interfaces. By continuous, rapid exchange of bound water with other free water molecules, these polymer films keep the surfaces separated while maintaining a high fluidity at the brush/brush interface at high compressions, thus leading to a very low coefficient of friction.

The following is taken from Encyclopedia Britannica, “Lubricants.”

Gaseous Lubricants

Lubrication with a gas is analogous in many respects to lubrication with a liquid, since the same principles of fluid-film lubrication apply. Although both gases and liquids are viscous fluids, they differ in two important particulars. The viscosity of gases is much lower and the compressibility much greater than for liquids. Film thicknesses and load capacities, therefore, are much lower with a gas such as air. In equipment that handles gases of various kinds, it is often desirable to lubricate the sliding surfaces with gas to simplify the apparatus and reduce contamination to and from the lubricant. The list of gases used in this manner is extensive and includes air, steam, industrial gases, and liquid-metal vapors.

Grease

Another form of oily lubricant is grease, a solid or semisolid substance consisting of a thickening agent in a liquid lubricant. Soaps of aluminum, barium, calcium, lithium, sodium, and strontium are the major thickening agents. Nonsoap thickeners consist of such inorganic compounds as modified clays or fine silicas, or such organic materials as arylureas or phthalocyanine pigments. Lubrication by grease may prove more desirable than lubrication by oil under conditions when 1) less frequent lubricant application is necessary, 2) grease acts as a seal against loss of lubricant and ingress of contaminants, 3) less dripping or splattering of lubricant is called for, or 4) less sensitivity to inaccuracies in the mating parts is needed.

c. Discuss the importance of viscosity.

The following is taken from Synthetic Performance Oil, “Motor Oil Viscosity, Why it’s Important.”

A fluid’s viscosity is important because it is directly related to its load-carrying capabilities. The greater a fluid’s viscosity, the greater the loads it can withstand. The viscosity of a fluid must be adequate to separate moving parts under normal operating conditions (temperature and speed).

Knowing that a fluid's viscosity is directly related to its ability to carry a load, one would think that the more viscous a fluid, the better it is. The fact is, the use of a high-viscosity fluid can be just as detrimental as using too light an oil.

Too low (thin or light) = Metal-to-metal contact (friction and wear), poor sealing, and increased oil consumption

Too high (thick or heavy) = Increased fluid friction, Reduced energy efficiency, higher operating temperature, and equipment starting difficulties particularly at cold temperatures.

The key is to select a fluid that is not too light and not too heavy.

d. Discuss the hazards to equipment associated with mixing different types of oils and greases.

The following is taken from Machinery Lubrication, "Managing the Risk of Mixing Lubricating Oils."

Today's high performance lubricants are specifically formulated with a carefully selected balance of performance additives and base stocks to match the lubrication requirements of the equipment in which they are used. When lubricants are mixed, this balance is often upset. Mechanical problems leading to shorter equipment life can occur, sometimes catastrophically.

Modern lubricants are sophisticated products, formulated to meet the demanding lubrication requirements of modern equipment. The old saying, "oil is oil" no longer applies. Mixing lubricants is fraught with danger to the equipment, to the business, and to profits. When in doubt, do not mix different lubricants. If mixing occurs accidentally, address the problem immediately. Do not be afraid to bring in an expert, whether it is the lubricant manufacturer, the additive supplier, or an independent consultant. The response to a situation where different lubricants are mixed will depend on the products in the mixture, the end-use application, the relative concentrations of products, and the total volume involved.

In its mildest form, mixing different lubricants may lead to a degradation of lubricant performance. Mixing the same API grades of synthetic passenger car motor oil and mineral oil-based engine oil won't damage the engine, but the performance features expected from the synthetic will be lost. At the other end of the spectrum, adding typical turbine oil to antiwear hydraulic oil in a hydraulic pump could spell disaster. Deposits may form that could increase wear and plug filters.

Why Formulation is Important

To understand why some mixed oils are okay but others are not, one must understand how modern lubricants are formulated. Most performance lubricants are a blend of base stocks and additives. The base stock is the oily portion of the lubricant, chosen for the physical and chemical properties needed in the final blend. Base stocks, in most industrial lubricants, are selected based on the requirements for viscosity, oxidation stability, fire-resistance, biodegradability, and water miscibility in the final product. They carry the load in hydrodynamic lubrication, remove heat and debris from friction and wear, and help seal out contaminants.

Most lubricants are formulated with mineral base stocks that are severely refined, low-wax, heavy distillate fractions of crude oil. They are relatively low cost, generally good solvents for most additives, available in a wide viscosity range, and compatible with a number of seal

materials. Synthetic base stocks are made by chemical manufacturers to impart special qualities to the finished oil. Polyalphaolefin, organic esters, glycols, and phosphate esters are examples of synthetics that are used to meet specific needs. Synthetics are used where the value of their special functional properties, oxidation stability, fire-resistance, etc., outweigh their cost.

Lubricants made with synthetic base stocks should not be mixed with products made with mineral oil, even if they are designed for the same application. The limited exceptions include some PAO and ester-based products. Even then, compatibility is often concentration-dependent. Deposits may form because of additive incompatibility or seal compatibility may be compromised.

Additives impart special performance features to the finished oil. The choice of additives and the balance among them differentiates antiwear hydraulic oil from turbine oil, for example. Some additives affect the physical properties of the finished lubricant. Others change the lubricant's chemical properties or are added for cosmetic purposes.

Lubricant Incompatibility

Some lubricants are incompatible because of differences in additive chemistry that lead to undesirable chemical reactions. If these oils are mixed, insoluble material may form and then deposit onto sensitive machine surfaces. For a hydraulic fluid, this could lead to lubricant starvation, valve failure or increased wear.

A second form of lubricant incompatibility is more insidious because no visible changes occur when the products are mixed. The problem appears only after the mixture is used in a piece of equipment that consequently fails or loses performance. For example, hydraulic/tractor fluid that is contaminated by motor oil can lead to brake chatter and failure in farm equipment. Optimum performance requires carefully balanced frictional and antiwear properties in the finished product that are upset when the lubricants are mixed.

Some incompatible lubricant mixtures may also affect synthetic rubber seals. Lubricants are formulated to be neutral to seals or cause them to swell slightly. Too much seal swell, seal shrinkage, or chemical deterioration may occur with some combinations of lubricants. Engine oils formulated with certain types of dispersants attack fluorocarbon seals. Lubricants contaminated by products containing ester base stocks may swell seals unacceptably. EP gear oils are known to deteriorate silicone seals.

Lubricant incompatibility is a chemistry problem. It has nothing to do with the manufacturers of the oil; two oils made by the same manufacturer may be incompatible. The most common cause of lubricant incompatibility that results in the formation of harmful solids is the reaction of an acidic component in one oil with a basic component in another. The reaction is accelerated by water and heat.

Oils containing acidic rust inhibitors are incompatible with oils containing basic rust inhibitors. When the two oils are mixed, especially when some water is present, a solid forms in the oil that reacts further with the oil to form a grease-like insoluble substance. This can clog filters, form deposits that interfere with lubrication, and interfere with demulsibility (water-oil separation).

One way to look at potential lubricant incompatibility is to classify lubricants as acidic or basic. Different lubricant manufacturers may use different additive chemistries to accomplish the same function, so caution is warranted. Check with the manufacturer to be sure.

Lubricants that require good demulsibility (water separation) should never be mixed with lubricants that contain dispersants or high concentrations of detergents. Small amounts of oil with good emulsion characteristics will destroy the water shedding properties of a highly demulsible lubricant. Rarely can the demulsibility be restored with additive supplements.

Lubricants formulated with non-zinc antiwear and antioxidant additives such as railroad engine oils and ashless or low-ash gas engine oils will cause engine damage if they are contaminated with lubricants containing zinc additives.

How to Avoid Lubricant Mixtures

Problems can occur all along the supply chain from the lubricant manufacturer to the end-use equipment. The manufacturer puts the wrong label on the drum. The marketer pumps oil into the wrong storage tank. The maintenance mechanic uses the wrong container to add makeup oil to the hydraulic fluid sump.

Incidents of lubricant mixing can occur without any evidence of negligence. A trucking firm changed the manufacturing source of heavy-duty diesel engine oil and upgraded to the newest API performance category. Within a few thousand miles, the oil was black and all oil condition-monitoring signs indicated that the oil needed to be changed. After investigating the problem with the bad oil, the lube engineer concluded that the replacement oil had such strong dispersancy that it was cleaning all the engine deposits generated from the use of the original lubricant. The remedy was to change oil at a shorter interval until the engines were clean, at which point the trucking firm realized the full benefits of the new oil.

Accidental mixing of oils can be minimized by sound practices—clearly labeling containers, checking manifests on oil shipments against the delivered products, supervising the unloading of bulk oil, and segregating oils that are known to be incompatible. Avoid using common hoses, funnels and containers to transfer lubricants from different families. For example, the same lubricant handling equipment can be used for different engine oils, but never transfer turbine oil with equipment used to transfer engine oils. Less than 0.2 percent engine oil can form emulsions in turbine oil. Before changing lubricant suppliers or accepting a new/improved product from the current supplier, obtain assurance that the new product is compatible with the old one. Ask what tests were conducted to demonstrate the product compatibility.

Fighting an Oil Mixing Problem

When an oil mixing problem occurs, certain prudent steps should be followed. For bulk oil, empty the tank before adding the new product. If products are incompatible, it may be necessary to flush the tank with diesel or base oil. If oil mixing is suspected, isolate the system. Thoroughly drain the oil from equipment that contains a suspected mixture. When seeking advice on how to handle the contaminated oil, provide the following information:

- Identity of each lubricant in the mixture, including name of manufacturer and brand name
- Volume of each component in the mixture
- Lubrication application
- Other lubricated equipment, often less severe applications, where the oil mixture might be used
- Where the mixed oil is located - one bulk tank or 10 gear boxes
- Ability to store oil mixture until final disposition can be determined

With this information, intelligent decisions can be made quickly to avoid equipment operating problems or damage, minimize downtime, and identify the best way to dispose of the oil mixture.

There are some simple tests to confirm an oil mixing problem even without access to a formal lubricant laboratory. Heat an oil mixture or two oils to test for compatibility and examine for clarity. If the mixture is cloudy, the oils are not compatible. To check further, add a small amount of water, mix thoroughly and continue heating. Allow the mixture to sit at room temperature for several hours. If a solid forms in the oil, they are incompatible.

To test for demulsibility (water-shedding properties) in a mixture, mix equal parts of warm oil and water in a bottle, shake thoroughly and allow the mixture to settle. If both oils have good demulsibility, the oil and water layers should separate cleanly with little or no emulsion between the layers. Even if these tests indicate that the oils are compatible, check with the manufacturer to see what other tests should be run before using the mixture in the equipment.

Before mixing lubricants or using lubricants that have been mixed, check with the oil manufacturer for the best course of action. Most importantly, look for ways to avoid the situation in the first place.

e. Discuss the use and importance of filters and filtration in lubricating systems.

The following is taken from Machinery Lubrication, “Matching Oil Filtration to Machine Requirements.”

Lube oil cleanliness is necessary for the reliable operation of machinery components such as bearings, gears, and hydraulics. Failure to adhere to cleanliness standards can result in sluggish operation, excessive wear, and premature failure. This article provides a brief overview of appropriate oil filtration practices and guidelines.

Typical Contaminants

While oil contamination takes many forms, the following three classifications cover the majority of industrial problems:

1. **Dirt**—Dust and solid contaminants creep in from the surrounding atmosphere. Contaminants could include metal chips from machining; rust and wear products from seals, bearings, and gears; core sand from castings; weld spatter from welding; paint flakes from painted surfaces; and soot from diesel engines.
2. **Water**—The most troublesome sources are often condensation, cooler leaks, gland leakage, and seal leakage.
3. **Sludge**—This forms primarily as a result of oxidation of the oil itself, especially at high temperatures. Accumulation of fine particles may also fill clearance spaces by silting, resulting in erratic operation and sticking of hydraulic system valves and variable flow pumps.

Different filtration specifications are required for each of these contaminants. With particulates, the maximum particle size should be kept below the minimum thickness of the fluid film.

With water, any free moisture may promote both rust and sludge by reacting with oil additives and metal surfaces. The critical limit of free water in the lubricant is the amount that causes the fluid film to fail in the load zone.

Filter Performance Factors

Before selecting an appropriate filter, the following must be examined:

- Demands imposed by machinery components—oil viscosity at the operating temperature, oil feed rate, and permissible pressure drop
- Expected size, type, and level of contaminants—the ingress and formation rate of environmental dust, metal chips, fly ash, wear particles, water, and/or other contaminants

f. Discuss the principle of operation of moisture separators.

The following is taken from GEM Equipment, “Moisture Separator.”

All air contains moisture in the form of water vapor. This water vapor begins to condense into condensate in the compressed air system when the air cools to saturation point. When this compressed air is used in the manufacturing plant, the moisture causes problems such as washing away of lubricants, increasing wear and tear, rust formation, corrosion etc. The easiest and most permanent solution for a moisture removal problem is the provision of a moisture separator.

After entering the moisture separator, the moist air hits the shell and then passes through a vortex generator, which generates the vortex motion of compressed air. The vortex generator is a fixed one and has a number of vanes. These vanes separate the moisture droplets by impingement separation method. Due to their density, the moisture droplets settle down into the dead zone below the arrestor. The moisture-free air is let out through the inner shell of the separator. The arrestor will not allow the compressed air to carry the removed moisture. An automatic drain valve (float type) is fitted to the dead zone, which drains the moisture condensate. A sight glass is provided for visually checking the level of moisture collected in the dead zone.

Mandatory Performance Activities:

- a. Given vendor data about a component, determine the proper class of lubricant for the component.**

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

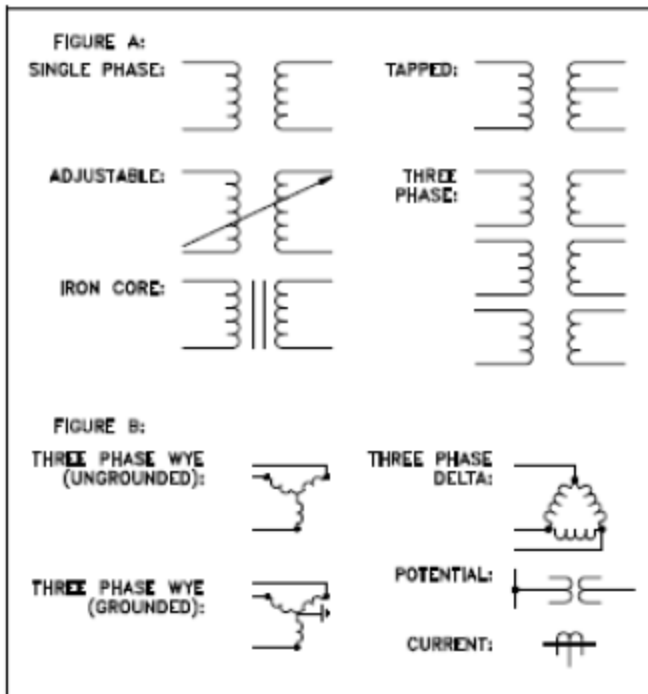
20. Mechanical systems personnel shall demonstrate a familiarity level knowledge of reading and interpreting electrical diagrams and schematics.

- a. Identify the symbols and/or codes used on engineering electrical drawings.**

Element a is performance based. The Qualifying Official will evaluate its completion. The following information from DOE-HDBK-1016/1-93, may be helpful.

To read and interpret electrical diagrams and schematics, the reader must first be well versed in what the many symbols represent. This section discusses the common symbols used to depict the many components in electrical systems. Once mastered, this knowledge should enable the reader to successfully understand most electrical diagrams and schematics. The information that follows provides details on the basic symbols used to represent components in electrical transmission, switching, control, and protection diagrams and schematics.

Transformers



Source: DOE-HDBK-1016/1-93

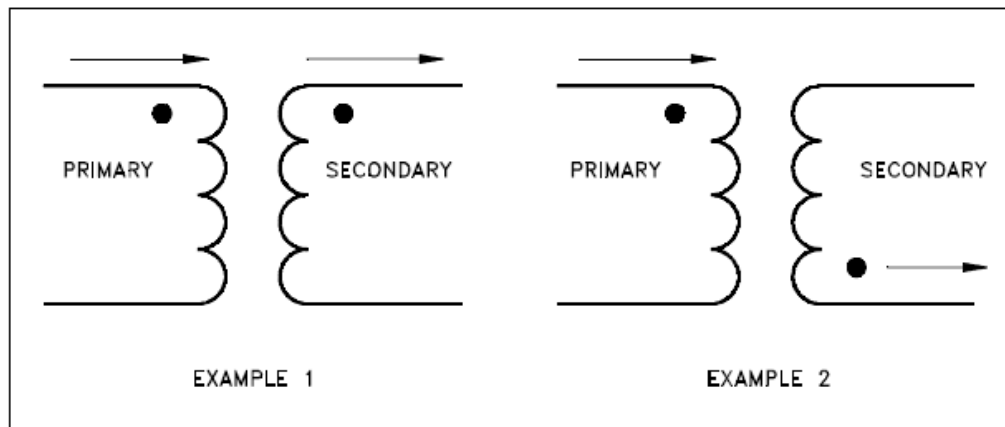
Figure 79. Basic transformer symbols

out of the transformer at the dotted end of the secondary coil. The current flow for a transformer using the dot symbology is illustrated in figure 80.

The basic symbols for the various types of transformers are shown in figure 79(A). Figure 79(B) shows how the basic symbol for the transformer is modified to represent specific types and transformer applications.

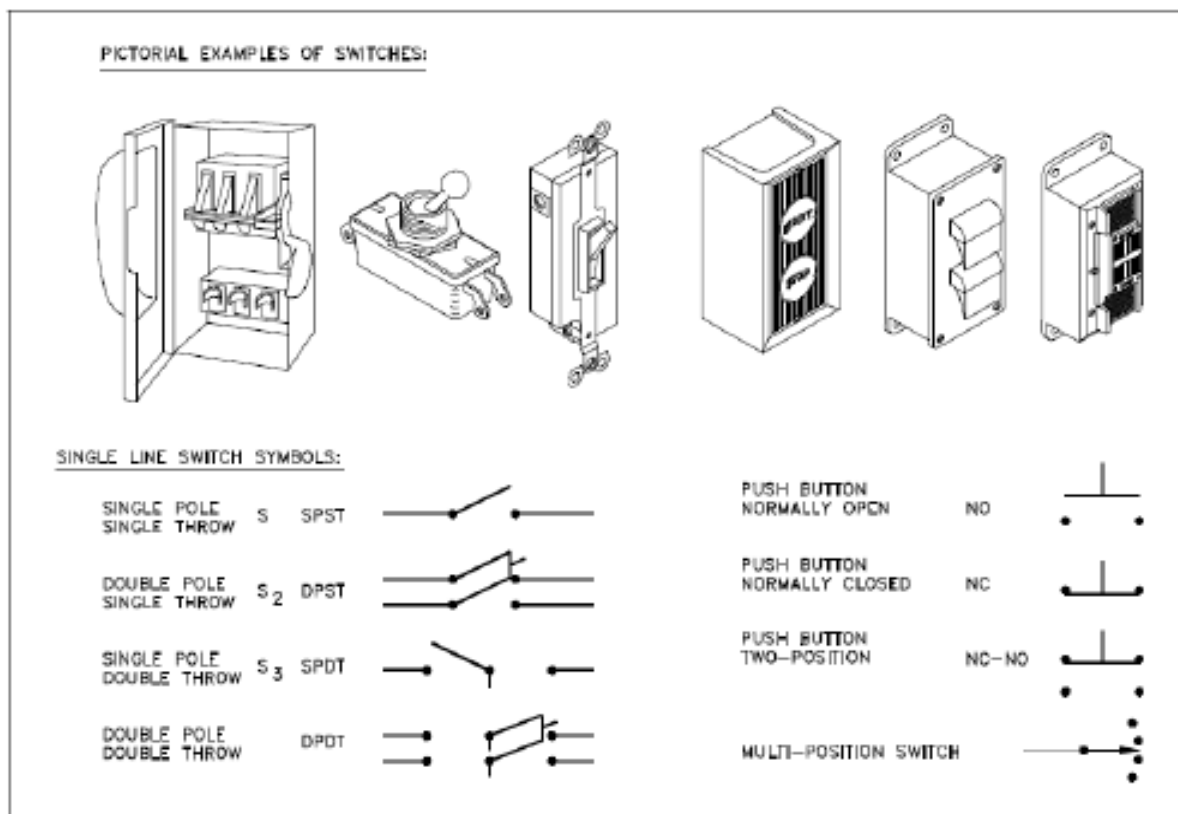
In addition to the transformer symbol itself, polarity marks are sometimes used to indicate current flow in the circuit. This information can be used to determine the phase relationship (polarity) between the input and output terminals of a transformer. The marks usually appear as dots on a transformer symbol, as shown in figure 80.

On the primary side of the transformer, the dot indicates current in; on the secondary side, the dot indicates current out. If at a given instant the current is flowing into the transformer at the dotted end of the primary coil, it will be flowing



Source: DOE-HDBK-1016/1-93

Figure 80. Transformer polarity



Source: DOE-HDBK-1016/1-93

Figure 81 Switches and switch symbols

Switches

Figure 81 shows the most common types of switches and their symbols. The term “pole,” as used to describe the switches in figure 81, refers to the number of points at which current can enter a switch. Single-pole and double-pole switches are shown, but a switch may have as many poles as it requires to perform its function. The term “throw” used in figure 81 refers to the number of circuits that each pole of a switch can complete or control.

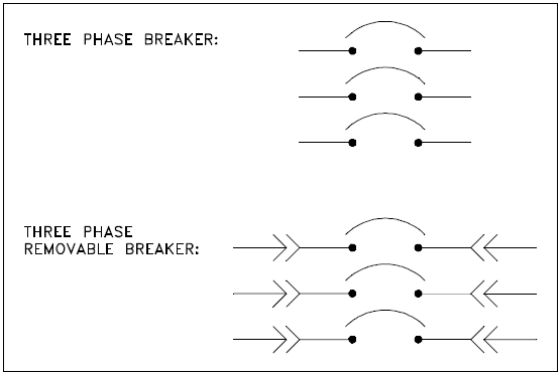
Figure 82 provides the common symbols that are used to denote automatic switches and explains how the symbol indicates switch status or actuation.

LIMIT SWITCH, DIRECT ACTUATED, SPRING RETURNED	
NORMALLY OPEN	
NORMALLY OPEN—HELD CLOSED	
NORMALLY CLOSED	
NORMALLY CLOSED—HELD OPEN	
OPEN SWITCH WITH TIME DELAY CLOSING (TDC) FEATURE	
CLOSED SWITCH WITH TIME DELAY OPENING (TDO) FEATURE	
OPEN SWITCH WITH TIME DELAY OPENING (TDO) FEATURE	
CLOSED SWITCH WITH TIME DELAY CLOSING (TDC) FEATURE	
FLOW ACTUATED SWITCH CLOSING ON INCREASE IN FLOW	
OPENING ON INCREASE IN FLOW	
LIQUID LEVEL ACTUATED SWITCH CLOSING ON RISING LEVEL	
OPENING ON RISING LEVEL	
PRESSURE OR VACUUM ACTUATED SWITCH CLOSING ON RISING PRESSURE	
OPENING ON RISING PRESSURE	
TEMPERATURE ACTUATED SWITCH CLOSING ON RISING TEMPERATURE	

Source: DOE-HDBK-1016/1-93

Figure 82. Switch and switch status symbology

When fuses, breakers, or switches are used in three-phase systems, the three-phase symbol combines the single-phase symbol in triplicate as shown in figure 83. Also shown is the symbol for a removable breaker, which is a standard breaker symbol placed between a set of chevrons. The chevrons represent the point at which the breaker disconnects from the circuit when removed.

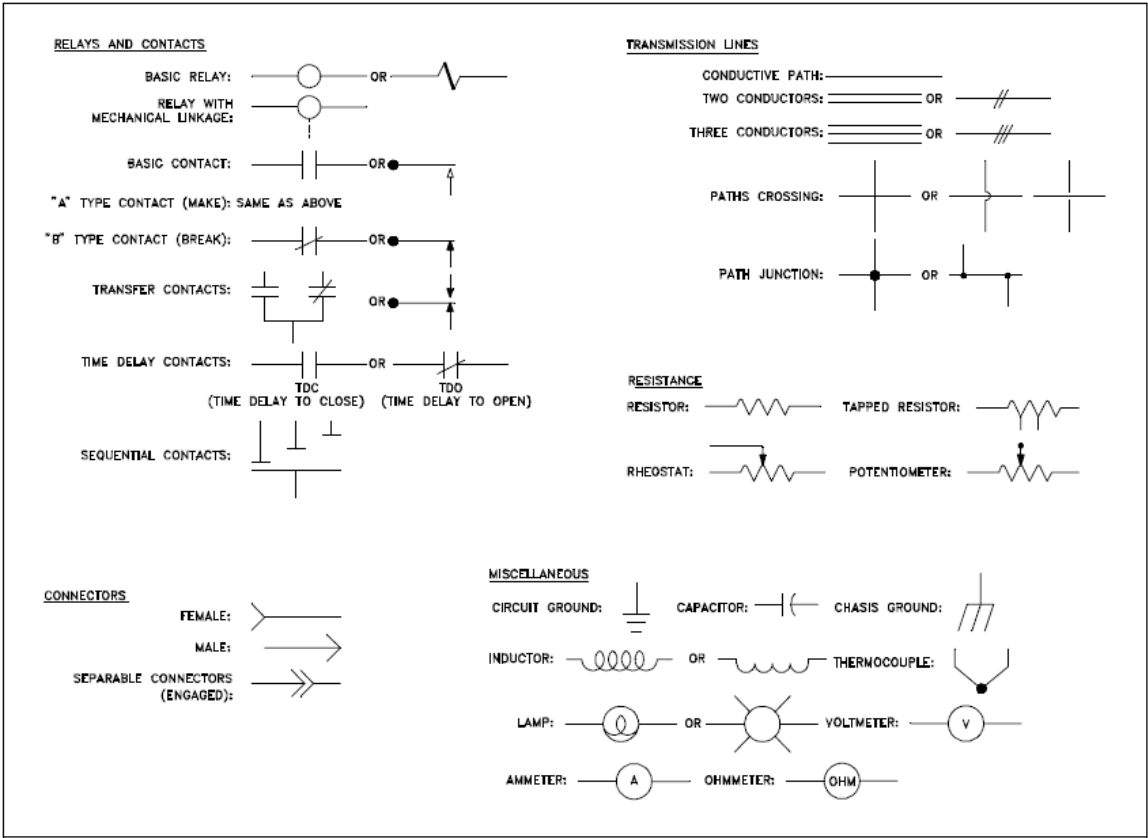


Source: DOE-HDBK-1016/1-93

Figure 83. Three-phase and removable breaker symbols

Relays, Contacts, Connectors, Lines, Resistors, and Miscellaneous Electrical Components

Figure 84 shows the common symbols for relays, contacts, connectors, lines, resistors, and other miscellaneous electrical components.

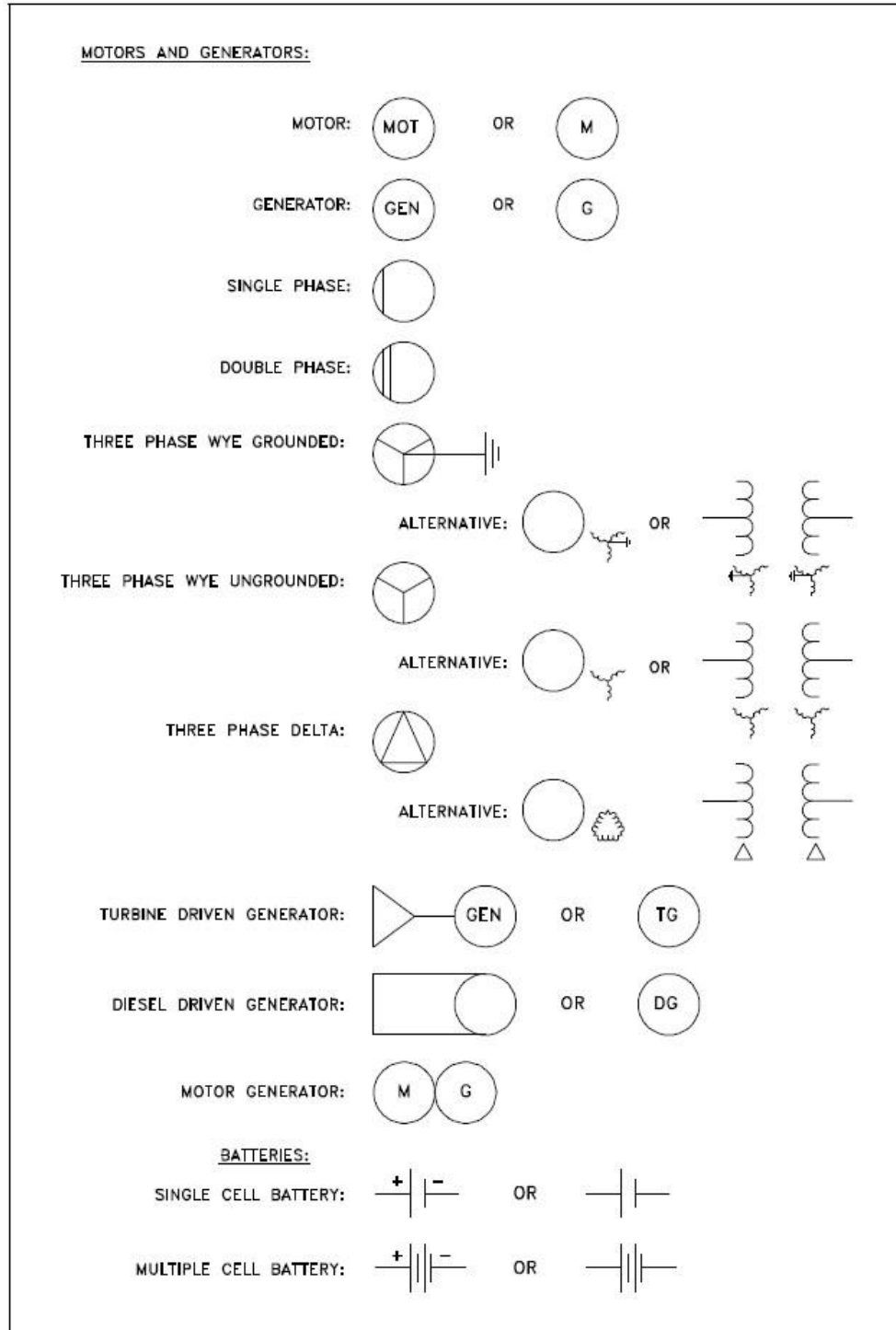


Source: DOE-HDBK-1016/1-93

Figure 84. Common electrical component symbols

Large Components

The symbols in figure 85 are used to identify the larger components that may be found in an electrical diagram or schematic. The detail used for these symbols will vary when used in system diagrams. Usually the amount of detail will reflect the relative importance of a component to the particular diagram.



Source: DOE-HDBK-1016/1-93

Figure 85. Large common electrical components

- b. Given a simple one-line diagram and initial conditions, identify the power sources and/or loads and their status.**
- c. Given an electronic block diagram, print, or schematic, identify the basic component symbols.**
- d. Given a relay ladder, explain the logic ties.**

Elements b through d are performance based. The Qualifying Official will evaluate their completion.

21. Mechanical systems personnel shall demonstrate a familiarity level knowledge of reading and interpreting electrical logic diagrams.

- a. Identify the symbols used on logic diagrams to represent the components.**

The following is taken from DOE-HDBK-1016/2-93.

There are three basic types of logic gates. They are AND, OR, and NOT gates. Each gate is a very simple device that only has two states, on and off. The states of a gate are also commonly referred to as high or low, 1 or 0, or True or False, where on = high = 1 = True, and off = low = 0 = False. The state of the gate, also referred to as its output, is determined by the status of the inputs to the gate, with each type of gate responding differently to the various possible combinations of inputs. Specifically, these combinations are as follows:

- AND gate—provides an output (on) when all its inputs are on. When any one of the inputs is off, the gate's output is off.
- OR gate—provides an output (on) when any one or more of its inputs is on. The gate is off only when all of its inputs are off.
- NOT gate—provides a reversal of the input. If the input is on, the output will be off. If the input is off, the output will be on.

Because the NOT gate is frequently used in conjunction with AND and OR gates, special symbols have been developed to represent these combinations. The combination of an AND gate and a NOT gate is called a NAND gate. The combination of an OR gate with a NOT gate is called a NOR gate.

- NAND gate—is the opposite (NOT) of an AND gate's output. It provides an output (on) except when all the inputs are on.
- NOR gate—is the opposite (NOT) of an OR gate's output. It provides an output only

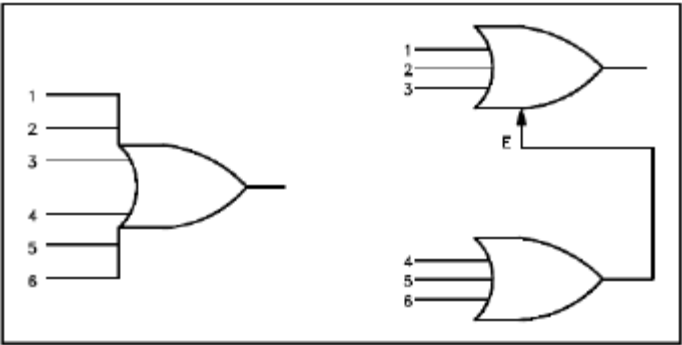
Figure 86 illustrates the symbols covering the three basic logic gates plus AND and NOR gates.

FUNCTION	IEEE/ ANSI	R113J	NEMA	MIL	IEC	ALLEN BRADLEY	G.E.
AND							
NAND							
OR							
NOR							
NOT							

Source: DOE-HDBK-1016/1-93

Figure 86 .Basic logic symbols

The AND gate has a common variation called a COINCIDENCE gate. Logic gates are not limited to two inputs. Theoretically, there is no limit to the number of inputs a gate can have. But, as the number of inputs increases, the symbol must be altered to accommodate the increased inputs. There are two basic ways to show multiple inputs. Figure 87 shows both methods, using an OR gate as an example. The symbols used in figure 85 are used extensively in computer logic diagrams.



Source: DOE-HDBK-1016/1-93

Figure 87. Conventions for depicting multiple inputs

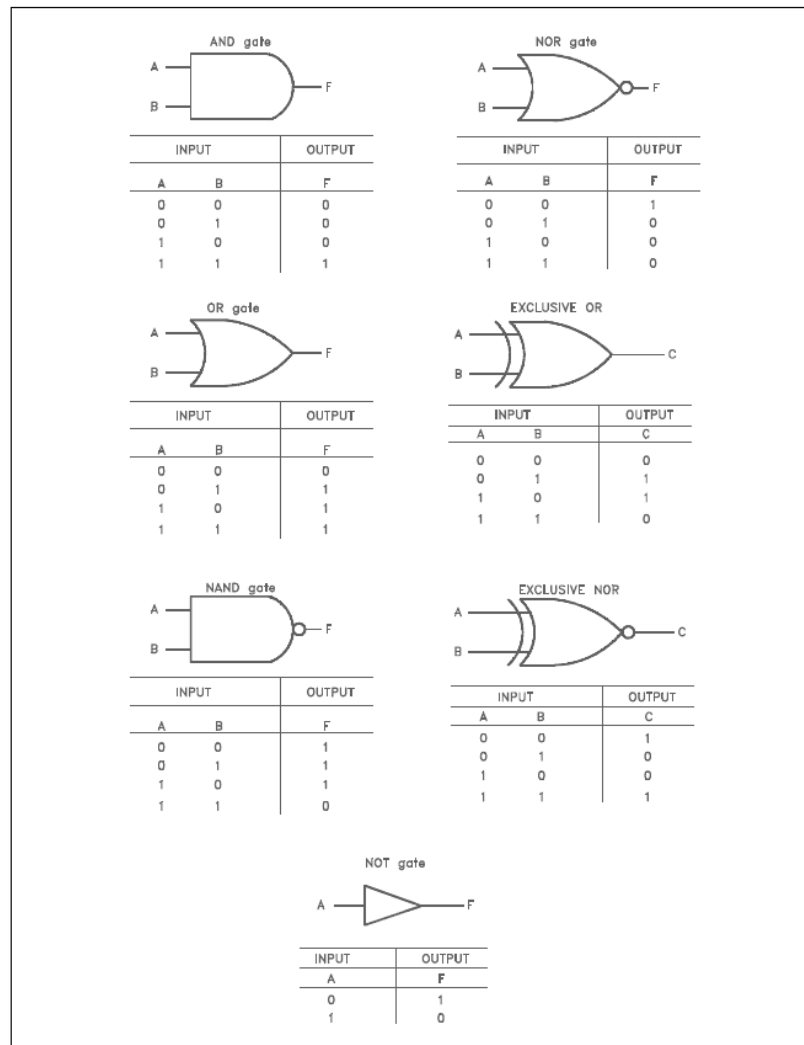
Video 48. Logic gates

<http://www.bing.com/videos/search?q=logic+gates&view=detail&mid=A1F0FB758EA9E821AC76A1F0FB758EA9E821AC76&first=0>

- b. Identify the symbols used to denote a logical “1” (or high) and a logical “0” (or low) as used in logic diagrams.

The following is taken from DOE-HDBK-1016/2-93.

When a logic gate has only two inputs, or the logic circuit to be analyzed has only one or two gates, it is fairly easy to remember how a specific gate responds and determine the output of the gate or circuit. But as the number of inputs and/or the complexity of the circuit grows, it becomes more difficult to determine the output of the gate or circuit. Truth tables, as illustrated in figure 88, are tools designed to help solve this problem. A truth table has a column for the input of each gate and column for the output of each gate. The number of rows needed is based on the number of inputs, so that every combination of input signal is listed (mathematically the number of rows is 2^n , where n = number of inputs). In truth tables, the on and off status of the inputs and outputs is represented by 0s and 1s: 0 = off and 1 = on. Figure 88 lists truth tables for the seven basic logic gates.



Source: DOE-HDBK-1016/1-93

Figure 88. Truth tables

Video 49. Truth tables

<http://vimeo.com/9651825>

- c. **Given a basic logic diagram and appropriate information, determine the output of each component and the logic circuit.**

Element c is performance based. The Qualifying Official will evaluate its completion.

- 22. Mechanical systems personnel shall demonstrate a working level knowledge of the requirements of DOE O 420.1B, Facility Safety, and the associated guidance of DOE G 420.1-1, Nonreactor Nuclear Safety Design Criteria and Explosives Safety Criteria Guide for Use with DOE O 420.1, Facility Safety; and DOE G 420.1-2, Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Nonnuclear Facilities.**
- a. **Discuss the general requirements of chapter I, Nuclear and Explosive Safety Design Criteria, of DOE O 420.1B.**

Integration of Design with Safety Analyses

Safety analyses must be used to establish

- the identity and functions of safety class and safety significant structures, systems, and components (SSCs); and
- the significance to safety of functions performed by safety class and safety significant SSCs.

Safety analyses must address

- hazards inherent to the facility and its activities;
- natural phenomena hazards (NPHs); and
- external man-induced hazards (factors such as proximity to airports, pipelines, hazardous traffic on roads or waterways, and adjacent facilities).

Safety analyses must be performed as early as practical in conceptual or preliminary design processes to ensure that required safety SSCs are specified in the final design.

Safety analyses must be performed in accordance with the requirements for safety analysis defined in DOE directives and technical standards for a documented safety analysis (DSA).

Nuclear Facility Design

Nuclear facility design objectives must include multiple layers of protection to prevent or mitigate the unintended release of radioactive materials to the environment, otherwise known as defense in depth. These multiple layers must include multiple physical barriers unless the basis for not including multiple physical barriers is documented in the DSA and approved by DOE.

Defense in depth must include all of the following:

- Choosing an appropriate site
- Minimizing the quantity of material at risk
- Applying conservative design margins and quality assurance
- Using successive physical barriers for protection against radioactive releases

- Using multiple means to ensure critical safety functions needed to
 - Control processes
 - Maintain processes in safe status
 - Confine and mitigate the potential for accidents with radiological releases
- Using equipment and administrative controls that
 - Restrict deviation from normal operations
 - Monitor facility conditions during and after an event
 - Provide for response to accidents to achieve a safe condition
- Providing means to monitor accident releases as required for emergency response
- Establishing emergency plans for minimizing the effects of an accident

Hazard category 1, 2, and 3 nuclear facilities must be sited, designed, and constructed in a manner that ensures adequate protection of the health and safety of the public, workers, and the environment from the effects of accidents involving radioactive materials release.

Hazard category 1, 2, and 3 nuclear facilities with uncontained radioactive material (as opposed to material determined by safety analysis to be adequately contained within drums, grout, or vitrified materials) must have the means to confine the uncontained radioactive materials to minimize their potential release in facility effluents during normal operations and during and following accidents. Confinement design considerations must include

- for a specific nuclear facility, the number, arrangement, and characteristics of confinement barriers as determined on a case-by-case basis;
- consideration of the type, quantity, form, and conditions for dispersing the radioactive material in the confinement system design;
- use of engineering evaluations, tradeoffs, and experience to develop practical designs that achieve confinement system objectives; and
- the adequacy of confinement systems to perform required functions as documented and accepted through the preliminary DSA and DSA.

Hazard category 1, 2, and 3 nuclear facilities must be designed to

- facilitate safe deactivation, decommissioning, and decontamination at the end of facility life, including incorporation of design considerations during the operational period that facilitate future decontamination and decommissioning;
- facilitate inspections, testing, maintenance, repair, and replacement of safety SSCs as part of a reliability, availability, and maintainability program with the objective that the facility is maintained in a safe state; and
- keep occupational radiation exposures within statutory limits and ALARA.

Facility process systems must be designed to minimize waste production and mixing of radioactive and non-radioactive wastes.

Safety SSCs and safety software must be designed, commensurate with the importance of the safety functions performed, to perform their safety functions when called upon and to meet the QA program requirements of either 10 CFR 830, “Nuclear Safety Management, subpart A, or DOE O 414.1D, *Quality Assurance*, as applicable.

Safety class electrical systems must be designed to preclude single-point failure.

New DOE nuclear reactors must comply with the requirements of DOE O 420.1B, and the design requirements of DOE Order 5480.30, *Nuclear Reactor Safety Design Criteria*.

Explosives Safety Design

New DOE explosives facilities and all modifications to existing explosives facilities must be designed consistent with the DOE explosives safety requirements established in DOE M 440.1-1A, DOE Explosives Safety Manual, and technical standards referenced in that manual. In particular, they must be designed according to the following:

- Department of Defense (DoD) TM5-1300, *Structural Design of Facilities to Resist the Effects of Accidental Explosions* (1990);
- DOE/TIC-11268, *Manual for the Prediction of Blast and Fragment Loading for Structures* (July 1992); and
- the following DoD Explosives Safety Board (DDESB) technical papers:
 - DDESB Technical Paper 12, Fragment and Debris Hazards, July 1975;
 - DDESB Technical Paper 13, Prediction of Building Debris for Quantity-Distance Siting, April 1991;
 - DDESB Technical Paper 15, Approved Protective Construction, June 2004;
 - DDESB Technical Paper 16, Methodologies for Calculating Primary Fragment Characteristics, dated December 1, 2003;
 - DDESB Technical Paper 17, DDESB Blast Effects Computer Version 5.0 User's Manual and Documentation, with accompanying program entitled DDESB Blast Effects Computer, Version 6.1.

Blast-resistant design to protect personnel and facilities must be based on the TNT equivalency of the maximum quantity of explosives and propellants permitted, increased by 20 percent according to DoD TM5-1300.

Implementation

For new facilities, an implementation plan must be submitted to the responsible Secretarial Officer or designee, describing the process for ensuring that facility design and construction will be in compliance with the nuclear facility safety requirements of DOE O 420.1B.

Deviations/exemptions from requirements must be appropriately documented, justified, and approved by DOE in accordance with the provisions stated in DOE O 420.1B.

b. Discuss the general requirements of chapter II, Fire Protection, of DOE O 420.1B.

General

Fire protection for DOE facilities, sites, activities, design, and construction must

- provide a level of safety sufficient to fulfill requirements for highly protected risk;
- prevent loss of safety functions and safety systems as determined by safety analysis and provide defense in depth; and
- meet or exceed applicable building codes for the region and National Fire Protection Association (NFPA) codes and standards as follows:
 - Facilities or modifications thereto must be constructed to meet codes and standards in effect, when design criteria are approved, otherwise known as the code of record (COR).
 - Provisions of subsequent editions of codes or standards (promulgated after the COR) must be met to the extent that they are explicitly stated to be applicable to existing

facilities. Other provisions of updated codes and standards must be applied to existing facilities when a construction modification takes place or when a potential for immediate risk to life, safety, or health has been identified through either the facility assessment or fire hazards analysis (FHA) review process, or during the construction review or permitting process.

FIRE PROTECTION PROGRAM

Acceptable, documented fire protection programs must be developed, implemented, and maintained to include the following elements and requirements:

- A policy statement that
 - incorporates fire protection requirements from this Order; related DOE directives; and other applicable Federal, state, and local requirements; and
 - affirms DOE's commitment to fire protection and fire suppression capabilities sufficient to minimize losses from fire and related hazards consistent with highly protected risk status in private industry.
- Comprehensive, written fire protection criteria or procedures that include
 - site-specific requirements;
 - staff organization, training, and responsibilities;
 - administrative responsibilities;
 - design, installation, operability, inspection, maintenance, and testing requirements;
 - use and storage of combustible, flammable, radioactive, and hazardous materials to minimize risk from fire;
 - fire protection system impairments;
 - smoking and hot work;
 - safe operation of process equipment; and
 - prevention measures that decrease fire risk.
- A system to ensure that fire protection program requirements are documented and incorporated in plans and specifications for new facilities and significant modifications to existing facilities.
- Documented review of plans, specifications, procedures, and acceptance tests by a qualified fire protection engineer.
- FHAs using a graded approach conducted for hazard category 1, 2, and 3 nuclear facilities, significant new facilities, and facilities that represent unique fire safety risks. The FHAs must be
 - performed under the direction of a qualified fire protection engineer;
 - reviewed every 3 years; and
 - revised when
 - changes to the annual DSA updates impact the contents in the FHA
 - a modification to an associated facility or process adds a significant new fire safety risk, or
 - the 3 year review identifies the need for changes.
- FHA conclusions incorporated into the DSA and integrated into design basis and beyond design basis accident conditions.
- Access to qualified, trained fire protection staff that includes fire protection engineers, technicians, and fire fighting personnel to implement the requirements of DOE O 420.1B.

- A baseline needs assessment (BNA) of the fire protection emergency response organization that
 - establishes the site fire fighting capabilities to provide
 - effective response to suppress all fires;
 - emergency medical and hazardous materials response capabilities; and
 - staffing, apparatus, facilities, equipment, training, pre-plans, offsite assistance, and procedures;
 - reflects applicable NFPA codes and standards; and
 - is updated at least every 3 years and in accordance with applicable NFPA code provisions and whenever a significant new hazard is introduced that is not covered by the current BNA.
- Site emergency plans, FHAs, and DSAs that incorporate BNA information.
- Pre-fire strategies, plans, and standard operating procedures to enhance the effectiveness of site fire fighting personnel.
- Procedures governing the use of fire fighting water or other neutron moderating materials to suppress fire within or adjacent to moderation controlled areas.
- Where no alternative exists to criticality safety restrictions on the use of water for fire suppression, the need for such restrictions is fully documented with written technical justification.
- A documented comprehensive fire protection self assessment and an assessment of contractors' programs performed by DOE every 3 years.
- Processes to identify, prioritize, and monitor the status of fire protection assessment findings, recommendations, and corrective actions until final resolution.
- A process for reviewing and recommending approval of fire safety equivalencies to any fire protection code or standard requirements to the DOE organization authority having jurisdiction for fire safety.
- Procedures governing fire fighting techniques to be used during deactivation, decontamination, and demolition phases, when applicable.

Fire Protection Design

A comprehensive fire protection design program for facilities and supporting systems must be developed, implemented, and maintained to include the following elements:

- A reliable and adequate supply of water for fire suppression
- Noncombustible construction materials for facilities exceeding the size limits established by DOE
- Complete fire-rated construction and barriers, commensurate with the applicable codes and fire hazards, to isolate hazardous areas and minimize fire spread and loss potential consistent with limits as defined by DOE
- Automatic fire extinguishing systems throughout all significant facilities and in all facilities and areas with potential for loss of safety class systems, significant life safety hazards, unacceptable program interruption, or fire loss potential in excess of limits defined by DOE
- Redundant fire protection systems in areas where
 - safety class systems are vulnerable to fire damage, and no redundant safety capability exists outside of the fire area of interest; or
 - the maximum possible fire loss exceeds limits established by DOE.

- In new facilities, redundant safety class systems
- A means to notify emergency responders and building occupants of a fire
- Emergency egress and illumination for safe facility evacuation in the event of fire as required by applicable codes or fire hazard analysis (FHA)
- Physical access and appropriate equipment that is accessible for effective fire department intervention
- A means to prevent the accidental release of significant quantities of contaminated products of combustion and fire fighting water to the environment, such as ventilation control and filter systems and curbs and dikes. Such features would only be necessary if required by the FHA or DSA in conjunction with other facility or site environmental protection measures
- A means to address fire and related hazards that are unique to DOE and not addressed by industry codes and standards. Mitigation features may consist of isolation, segregation, or the use of special fire control systems as determined by the FHA
- Fire protection systems designed such that their inadvertent operation, inactivation, or failure of structural stability will not result in the loss of vital safety functions or inoperability of safety class systems as determined by the DSA.

c. Discuss the general requirements of chapter IV, Natural Phenomena Hazards Mitigation, of DOE O 420.1B.

DOE facilities and operations must be analyzed to ensure that SSCs and personnel will be able to perform their intended safety functions effectively under the effects of natural phenomena hazard (NPH). Where no specific requirements are identified, model building codes or national consensus industry standards must be used consistent with the intended SSC functions.

Natural Phenomena Mitigation Design

Facility SSCs must be designed, constructed, and operated to withstand NPH and ensure

- confinement of hazardous materials;
- protection of occupants of the facility, and members of the public;
- continued operation of essential facilities; and
- protection of government property.

The design and construction of new facilities and major modifications to existing facilities and SSCs must address

- potential damage to and failure of SSCs resulting from direct and indirect NPH events;
- common cause/effect and interactions resulting from failures of other SSCs; and
- compliance with seismic requirements of Executive Order (E.O.) 12699, *Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction*.

Additions and modifications to existing DOE facilities must not degrade SSC performance during an NPH occurrence.

EVALUATION AND UPGRADE REQUIREMENTS FOR EXISTING DOE FACILITIES
SSCs in existing DOE facilities must be evaluated when there is a significant degradation in the facility safety basis. Evaluations must address the safety significance of the SSCs and the seismic requirements of E.O. 12941, "Seismic Safety of Existing Federally Owned or Leased Buildings."

If the evaluation of existing SSCs identifies NPH mitigation deficiencies, an upgrade plan must be implemented on a prioritized schedule based on the safety significance of the upgrades, time or funding constraints, and mission requirements.

NPH ASSESSMENT.

Facility design and evaluation criteria must address the potential types of NPH occurrences. The NPH assessment must use a graded approach commensurate with the potential hazard of the facility.

NPH assessment for new facilities must use a graded approach that considers the consequences of all types of NPHs. Site-wide information may be considered when appropriate.

NPH assessments must be reviewed and upgraded as necessary for existing sites/facilities following significant changes in NPH assessment methodology or site-specific information.

An NPH assessment review must be conducted at least every 10 years and must include recommendations to DOE for updating the existing assessments based on significant changes found in methods or data. If no change is warranted from the earlier assessment, then only the review needs to be documented.

SEISMIC DETECTION

Facilities or sites with hazardous materials must have instrumentation or other means to detect and record the occurrence and severity of seismic events.

POST-NATURAL PHENOMENA PROCEDURE

Facilities or sites with hazardous materials must have procedures for inspecting facilities for damage from severe NPH events and placing a facility into a safe configuration when damage has occurred.

d. Discuss the scope and general content of DOE G 420.1-1 and DOE G 420.1-2.

DOE G 420.1-1

DOE G 420.1-1 provides guidance on the application of requirements for nonreactor nuclear facilities and explosives facilities of DOE O 420.1B. The following guidelines were established for the development of this guide:

- DOE G 420.1-1 guide provides guidance on implementing the requirements stated in DOE O 420.1B as they apply to the design aspects for nuclear safety of nonreactor nuclear facilities and safety requirements for explosives facilities. The guidance provided in DOE G 420.1-1 is restricted to the requirements identified in DOE O 420.1B.
- Safety analyses performed according to DOE-STD-3009-94 *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*. Establish the identification, function, and performance of safety SSCs and must be conducted early in the design process.
- Applicable current rules, standards, and orders will be referenced herein, and text and requirements from these documents will not be repeated.
- Same-subject information will be grouped in a single section and cross-referenced elsewhere as required.
- Management and policy requirements will not be included in this document.

DOE G 420.1-2

DOE G 420.1-2, *Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Nonnuclear Facilities* is approved for use by the DOE Office of Nuclear Safety Policy and Standards and is available for use by all DOE elements and their contractors.

DOE G 420.1-2 provides guidance in implementing the NPH mitigation requirements of DOE O 420.1B

DOE G 420.1-2 is to be used with DOE O 420.1B; the current/latest versions of the NPH DOE Standards 1020, 1021, 1022, and 1023; and Interagency Committee on Seismic Safety in Construction standards/guides RP 1, 2.1A, 3, 4, 5.

- 23. Mechanical systems personnel shall demonstrate a working level knowledge of safety in design as described and required in DOE O 413.3A, Program and Project Management for the Acquisition of Capital Assets, and DOE M 413.3-1, Project Management for the Acquisition of Capital Assets, and DOE-STD-1189-2008, Integration of Safety into the Design Process.**
- a. Discuss the mechanical systems reviewer's responsibilities at each critical decision point as described in DOE O 413.3A.**

[Note DOE O 413.3A has been superseded by DOE O 413.3B.]

Reviews are an important project activity and must be planned as an integral part of the project and tailored appropriate to project risk, complexity, duration, and critical decision (CD) or phase. The following is a summary of key reviews organized by critical decision.

CD-0—Mission Validation Independent Project Review

A mission validation independent project review is a limited review prior to CD-0 for major system projects. It validates the mission need and the cost range. A value study may also be conducted, as appropriate, to assist in CD-0.

CD-1—Acquisition Strategy Review

Acquisition Strategies for Major System Projects must be sent to the Energy Systems Acquisition Advisory Board Secretariat for review by the Office of Engineering and Construction Management prior to scheduling CD-1 decisional briefings. The Federal program manager, Federal project director (FPD), and contracting officer (CO) must concur with the acquisition strategy prior to the Office of Engineering and Construction Management review. The Office of Engineering and Construction Management will provide a recommendation to the appropriate Program Secretarial Officer or Deputy/Associate Administrator who holds approval authority. Approval of the acquisition strategy does not constitute approval required by the Offices of Procurement and Assistance Management (DOE or NNSA, as applicable) for specific contract clearance purposes, including contract acquisition plans.

TECHNICAL INDEPENDENT PROJECT REVIEW

Prior to CD-1 approval, the Program Secretarial Officer will perform a technical independent project review to ensure safety and security are effectively integrated into design and construction for high-risk, high-hazard, and hazard category 1, 2, and 3 nuclear facilities. The review should ensure safety documentation is complete, accurate, and reliable for entry into the next phase of the project.

DESIGN REVIEWS

Design reviews are an integral part of a project. Beginning at CD-1 and continuing through the life of the project, as appropriate, design reviews are performed by individuals external to the project. Design reviews are performed to determine if a product (drawings, analysis, or specifications) is correct and will perform its intended functions and meet requirements.

Design reviews must be conducted for all projects and must involve a formalized, structured approach to ensure the reviews are comprehensive, objective, and documented.

CD-2—Performance Baseline Validation Review

A performance baseline validation review is required to provide reasonable assurance that the project can be successfully executed. Independent project reviews are required to validate the performance baseline for projects with a total project cost (TPC) or environmental management TPC less than \$100 million. The acquisition executive may request an external independent review in lieu of an independent project review through the Office of Engineering and Construction Management, and must do so if the acquisition executive has no Project Management Support Office to perform the review. For all projects with a TPC or environmental management TPC greater than or equal to \$100 million, the Office of Engineering and Construction Management uses the external independent review in support of the performance baseline validation. As part of the external independent review, either an independent cost estimate or independent cost review is employed.

CD-3—Construction or Execution Readiness Review

An external independent readiness review must be performed by the Office of Engineering and Construction Management on major system projects to verify execution readiness. At a minimum, this review verifies the readiness of the project to proceed into construction or remedial action. The findings of the execution readiness review and any corrective actions must be presented to the Secretarial Acquisition Executive as a part of CD-3 approval. A similar independent project review may be performed by the appropriate Program Secretarial Officer for Non-Major System Projects as requested by the acquisition executive.

CD-4—Operational Readiness Review or Readiness Assessment

As appropriate, an operational readiness review or readiness assessment is conducted prior to approving CD-4.

b. Discuss the mechanical systems reviewer's responsibilities as stated in DOE M 413.3-1.

[Note: DOE M 413.3-1 has been canceled.]

c. Discuss the mechanical systems reviewer's responsibilities as a member of the Integrated Project Team as stated in DOE-STD-1189-2008.

As stated in DOE-STD-1189-2008, DOE O 413.3B, requires the formation of an Integrated Project Team (IPT), to be led by a Federal project director. Subgroups to the IPT may be chartered during the project, including a contractor IPT led by the project manager.

The following is taken from DOE G 413.3-18A.

FPD Support

The first expectation of an IPT is to support the FPD by providing individual expertise and capabilities in the various project disciplines. Each IPT member acts as liaison between the IPT and their functional organizations. They should be supported to act on behalf of the FPD. The FPD will formally delineate the limits of authority and accountability for each member, based on their function in the IPT and their experience. Delegation, properly employed, reduces the burden on the FPD while better using the capabilities of the individual members of the IPT.

Acquisition Planning

DOE O 413.3B sets the requirement that the IPT work with the contracting officer (CO) to develop a project acquisition strategy (AS) or acquisition plan (AP), as applicable. The CO also works with the IPT to develop solicitations to evaluate and award mission-oriented contracts. DOE O 413.3B also requires that an AS be prepared as a pre-requisite for CD-1 and that an updated AS be approved prior to CD-2, if there is any major change to the acquisition approach.

The OMB capital programming guide (CPG) offers additional suggestions for an IPT to consider that are meant to use input from the private sector. These suggestions supplement project and acquisition planning activities expected by the FPD and/or the CO with others in the IPT.

The OMB CPG recommends that the IPT take ownership of supporting the planning process and determine what is available in the private sector and whether there are items that could be used as-is or modified to satisfy the needs of the project. Specifically, OMB recommends that the IPT perform studies as follows: After CD-0 approval, DOE management should provide the IPT with an estimate of the range of funds that may be available for the project. The IPT should then conduct surveys to determine if the private sector can provide requirements for the project that will satisfy the mission need within the funding constraint. Emphasis should be placed on generating innovation and competition and the use of existing items to satisfy the mission need. The IPT should determine: 1) availability, 2) affordability, 3) cost and benefits, 4) sustainable design principles, and 5) risk. In conducting its surveys, the IPT should seek information by reviewing published information, talking with other agencies that have conducted similar investigations, or by directly approaching the private sector for information. The IPT should be empowered to engage potential suppliers as advisors. The government can provide a general description of the mission need and invite potential offerors to submit information. The IPT should keep abreast of the latest capabilities and performance through professional associations, trade journals, advertisements, sales brochures, and the like. The IPT should be heavily involved in ensuring that the published requirements accurately reflect what is desired and should participate in determining the contract incentives.

Environmental, Safety, and Health; Security; and Quality Assurance (QA)

The extent of the duration of an IPT's involvement in environmental, safety, and health (ES&H); security; and QA depends upon the nature of the project (e.g. scope, complexity, nuclear, etc.) but should be included, even at minimum representation at certain stages. While this involvement extends in various capacities over the length of the project, the identification and definition of requirements expect significant IPT involvement in the period between CD-0 and CD-1. If the requirements are not defined early, the result can be costly downstream rework and delay.

The strong implementation of a quality assurance program (QAP) greatly enhances the successful execution of a project. Conversely, a poorly implemented QAP significantly increases project risk and the potential for ES&H consequences. The IPT will determine the QA requirements for a project and monitor compliance with those requirements as the project progresses.

Other Planning

DOE O 413.3B does not specify the IPT's roles and responsibilities for developing the project execution and risk management plans; it assigns that responsibility to the FPD. However, the IPT should be involved in support of the FPD in developing both of these plans. The IPT should also be directly leading the development of other project documentation such as the integrated safety management plan, the preliminary hazards analysis, and components of the QA Program.

Defining Key Parameters

DOE O 413.3B requires the IPT to identify and define appropriate and adequate project technical scope, schedule, and cost parameters. The technical scope should define what the project is to accomplish. If processes are involved, the scope should define the state of the process output, the input requirements and parameters, and the throughput.

Schedule parameters should include how long the project will take. Various amounts of schedule detail may be provided at this time. The IPT needs to recognize the link between the length of the schedule and the availability of money—a longer funding profile will lead to a longer schedule.

Cost parameters should include total project cost (TPC), contingency, and estimate of management reserve. The IPT should recognize the link between total cost and funding profile. A longer funding profile will generally lead to a larger TPC because of inefficiencies and load. The cost parameters should also include an allowance for any subject matter experts and Federal project staff augmentation.

DOE O 413.3B requires the IPT to establish by CD-2 minimum key performance parameters (KPP) that reflect the key technical, schedule, and cost parameters for the project. Additionally, for NNSA projects, KPPs also need to be identified in the program requirements document. KPPs are developed as the result of an analysis that leads the IPT to conclude that a particular project concept is the appropriate solution capable of meeting the required mission need.

The OMB CPG also reiterates that it is incumbent upon the agency IPT to clearly define the performance requirements and estimated costs for major acquisitions before request for proposal are issued. The IPT must also develop sound cost estimates. The IPT must ensure that the proposals and in-house estimates clearly recognize the amount and impact of risk on cost, schedule, and technical effort.

Thus, the IPT is responsible for identifying the functional and operational requirements for a project, alternative approaches, level of resources required, and the optimal path forward.

The IPT also has a responsibility to assure that the technology is ready to support the project. DOE O 413.3B states that for major system projects where new critical technologies are being deployed, the IPT shall complete a technical readiness assessment and technology maturation plan, as appropriate. These assessments are also encouraged for lower cost projects where new technologies may exist.

Managing Interfaces

DOE O 413.3B assigns the IPT the responsibility to ensure project interfaces are identified, defined, and managed to completion.

Overseeing Project Performance

DOE O 413.3B requires the IPT to oversee project performance by participating in and performing a variety of reviews, specifically: perform periodic reviews and assessments of project performance and status against established performance parameters, baselines, milestones, and deliverables; plan and participate in project reviews, audits, and appraisals as necessary; participate, as required, in operational readiness reviews or readiness assessments.

DOE senior leadership directed that peer reviews be conducted at least once a year for large or high visibility projects, and more frequently for more complex projects or those experiencing performance challenges. DOE leadership states that project management professional development and departmental knowledge management is the ultimate result; enhancement to project execution performance over time is the by-product. When the IPTs performance oversight responsibilities are viewed in total, it is clear that the IPT serves as a primary tool for tracking and controlling project progress, and that the members of the IPT should be skilled in recognizing the early warning signs of any emerging performance problems.

Change Requests

DOE O 413.3B requires the IPT to review change requests, as appropriate, and support change control boards as requested. Proper change control procedure, as defined in the project execution plan and related project documentation should guide the IPT. The IPT should prepare an analysis of the estimated changes in cost, schedule, and performance goals if the existing goals will not be achieved and determine the reasons for cost, schedule or performance deviations and evaluate whether the corrective actions are likely to be effective. The IPT should prepare an analysis of the estimated changes in cost, schedule, and performance deviations that exceed the existing goals, although more to assess proper project delivery than assess needed corrective actions.

Project Deliverables

DOE O 413.3B also assigns the IPT responsibility for reviewing, and in some instances, recommending approval (or disapproval) of key project deliverables.

The IPT must review all CD packages and recommend approval/disapproval; review and comment on project deliverables; and support preparation, review, and approval of project completion and closeout documentation.

It is important to appreciate the effort required to prepare for and perform these actions and not underestimate the time and personnel needed to perform each review. One way to minimize the

effort required is to adequately prepare for the review. For some situations, this goes well beyond planning for the review proper. It involves steps that will help ensure that the items being reviewed have met the specifications and prerequisites before they are delivered.

One approach is for the IPT to use a “rolling wave” concept where, for example, in a design review, prior to proceeding with a design, the IPT should ensure that: all system and component level functional and operating requirements have been identified, checked and approved; full design criteria for the SSCs have similarly been identified, checked and approved; and criteria for the deliverables have been developed and agreed to by the IPT.

Another approach is to involve more of the contractor staffing in the design/design review process, in addition to the role that the IPT members play. The IPT should ensure the proper activities are controlled through procedures and verify performance through the contractor assurance system, but the staffing supplement offered by the contractor may prove beneficial.

However, IPT members should neither be permitted to formally review their own work nor review the work of others in their own functional organization. Also, the CO is expected to remain vigilant to enforce performance terms of the contract, especially so if more of the contractor staffing are involved.

- 24. Mechanical systems personnel shall demonstrate a working level knowledge of the following standards related to natural phenomena hazards:**
- **ASCE/SEI 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities**
 - **DOE-STD-1020-2002, Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities**
 - **DOE-STD-1021-93, Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components**
 - **DOE-STD-1022-94, Natural Phenomena Hazards Site Characterization Criteria**
- a. Describe the purpose and scope and the application of the provisions detailed in the listed standards.**

ASCE/SEI 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI) 43-05 provides stringent design criteria for nuclear facilities. Due to the potential risk associated with nuclear hazards, it is desirable that nuclear facilities have a lower probability that structural damage will be caused by earthquake than do conventional facilities. The goal of this standard is to ensure that nuclear facilities can withstand the effects of earthquake ground shaking with desired performance. This standard will be of use to any designer or analyst involved in the design of new nuclear structures, systems, or components.

DOE-STD-1020-2002, Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities

This natural phenomena hazard standard provides criteria for design of new SSCs and for evaluation, modification, or upgrade of existing SSCs so that DOE facilities safely withstand the effects of NPHs such as earthquakes, extreme winds, and flooding.

DOE-STD-1020-2002 provides consistent criteria for all DOE sites across the United States. These criteria are provided as the means of implementing DOE O 420.1 and the associated Guides, and E.O. 12699 and E.O. 12941 for earthquakes.

The design and evaluation criteria presented in DOE-STD-1020-2002 control the level of conservatism introduced in the design/evaluation process so that earthquakes, wind, and flood hazards are treated on a consistent basis. These criteria also employ a graded approach to ensure that the level of conservatism and the rigor in design/evaluation are appropriate for facility characteristics such as importance, hazards to people onsite and offsite, and threat to the environment. For each natural phenomena hazard covered, these criteria consist of the following:

- Performance categories and target performance goals as specified in appendices B and C of DOE-STD-1020-2002
- Specified probability levels from which natural phenomena hazard loading on structures, equipment, and systems is developed
- Design and evaluation procedures to evaluate response to NPH loads and criteria to assess whether or not computed response is permissible

DOE-STD-1021-93, Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components

DOE-STD-1021-93 provides guidelines to be used for NPH performance categorization of SSCs, and recommends systematic procedures to implement these guidelines. It applies to all DOE facilities that are covered by DOE O 420.1B. Title 10 CFR 830 requires the use of a graded approach in performing safety analysis and evaluation of DOE facilities for normal operating and accident conditions, including accidents caused by NPH events. DOE G 420.1-2 uses this graded approach and requires, for the purpose of NPH design and evaluation, placing the SSCs comprising the DOE facilities into five NPH performance categories.

DOE-STD-1022-94, Natural Phenomena Hazards Site Characterization Criteria

The requirements given in DOE-STD-1022-94 should be used in conjunction with other DOE Orders and standards such as International Building Code, IBC 2012; ASCE-4, *Seismic Analysis of Safety-Related Nuclear Structures*; Federal Emergency Management Agency. FEMA 368, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings and Other Structures*. 2000., *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings and Other Structures*; etc.

DOE-STD-1022-94 is approved for use by all DOE departments and contractors. The preparation of this document was conducted by the Fission Energy and System Safety Program of Lawrence Livermore National Laboratory under the direction of the DOE NPH subcommittee and NPH standard managers from the offices of EH-53 and NA-53.

- b. Briefly describe the levels of function required for mechanical systems following a natural phenomena hazard and the safety measures and design features commonly used as safeguards against natural hazards. Include HVAC systems, fluid systems, and diesel generator systems in the discussion.**

c. Identify which systems require emergency power to remain functional following loss of normal power.

The requirements related to elements b and c are site specific. Levels of function and systems that require emergency power to remain functional following loss of normal power will vary from site to site. The Qualifying Official will evaluate the elements' completion.

25. Mechanical systems personnel shall demonstrate a working level knowledge of DOE maintenance management requirements as defined in DOE O 433.1A, Maintenance Management Program for DOE Nuclear Facilities.

[Note: DOE O 433.1A has been superseded by DOE O 433.1B.]

a. Explain DOE's role in the oversight of contractor maintenance operations.

The following is taken from DOE O 433.1B.

The following are field office managers' responsibilities for maintenance operations oversight:

- Ensure that maintenance activities and programs at hazard category 1, 2, and 3 nuclear facilities under their purview are conducted according to DOE O 433.1B.
- Ensure that sufficient resources are requested to meet the requirements of DOE O 433.1B and to ensure that safety SSCs are sufficiently maintained to perform their assigned safety function.
- Ensure that cost-effective nuclear maintenance management programs (NMMPs) are developed and implemented for all hazard category 1, 2, and 3 DOE nuclear facilities.
- Ensure that the requirements of DOE O 433.1B are incorporated into contracts, subcontracts, and support services contracts for hazard category 1, 2, and 3 nuclear facilities as appropriate
- Notify COs when contracts are affected by DOE O 433.1B.
- Review and approve NMMP program description documentation that demonstrates compliance with the specific requirements in the contractor requirements document, attachment 1.
- Conduct comprehensive self assessments and assessments of contractor maintenance management programs.

b. Identify the key elements of a contractor maintenance plan required by DOE O 433.1A.

[Note: DOE O 433.1A has been superseded by DOE O 433.1B. The contractor maintenance plan has been replaced by the nuclear maintenance management program.]

The following is taken from DOE O 433.1B.

The general requirements for a nuclear maintenance management program include the following:

- Federal and contractor organizations responsible for hazard category 1, 2, or 3 nuclear facilities must develop and implement a NMMP through tailored application of the specific requirements in DOE O 433.1B. The NMMP must describe the safety management program for maintenance and the reliable performance of SSCs that are part of the safety basis at hazard category 1, 2 and 3 DOE nuclear facilities.

- Federal and contractor organizations must conduct all maintenance of SSCs that are part of the safety basis in compliance with an approved NMMP.
 - Federal and contractor organizations must ensure that equivalencies and exemptions from the maintenance management program elements are identified, formally documented with supporting justification, and approved. Central technical authority (CTA) or designee concurrence is required for exemptions and equivalencies to DOE O 433.1B for nuclear facilities.
 - Federal and contractor organizations must implement the NMMP through Federal or contractor-approved documents, respectively. This is normally accomplished with a manual or a set of implementing procedures.
 - Federal and contractor organizations must submit NMMP description documentation to DOE/NNSA for review and approval prior to the startup of new hazard category 1, 2, and 3 nuclear facilities and at least every three years for all nuclear facilities. NMMP description documentation must be, at a minimum, an applicability matrix or a combination of multiple documents. The following elements must be covered:
 - Correlation of the requirements in this attachment to the applicable facilities
 - Correlation of the implementing documents to the specific requirements in DOE O 433.1B
 - Documentation of the basis for applying a graded approach, if applicable.
 - Federal and contractor organizations with previously approved maintenance management program documentation must submit either an addendum or page changes to the program documentation to reflect the changes made as a result of the implementation of requirements in this attachment. If no changes are needed, a memorandum to that effect may be submitted as the addendum. Changes must be submitted to DOE/NNSA for approval within 90 days from the date of inclusion of the requirements in this attachment in the contract.
 - Federal and contractor organizations must conduct assessments of NMMP implementation, at least every three years or less frequently if directed by the DOE/NNSA so in accordance with DOE O 226.1B and 10 CFR 830, subpart A.
 - Federal and contractor organizations must ensure that NMMPs are identified in the applicable DSA according to 10 CFR 830.204, “Documented Safety Analysis”.
 - Federal and contractor organizations must review proposed changes to the NMMP, which could affect the performance of safety SSCs, as part of the ongoing unreviewed safety question (USQ) process. This review is intended to evaluate whether safety SSCs are maintained and operated within the approved safety basis, as required by 10 CFR 830.203, “Unreviewed Safety Question Process.”. Changes which would result in a positive USQ must be submitted to DOE/NNSA for approval prior to the change taking effect.
 - These requirements will be fully implemented within 1 year of its issuance, unless a different implementation schedule is approved by the secretarial office (SO) with concurrence of the central technical authority (CTA).
- c. Describe configuration control and its relationship to the maintenance work control process and the maintenance history file.**

The following is taken from DOE G 433.1-1A.

According to DOE O 433.1B, the NMMP must include incorporation of the configuration management program to control approved modifications and to prevent unauthorized modifications to Safety SSCs. Implementation of configuration management (CM) programs shall be according to the requirements of DOE O 420.1B.

The NMMP should address the following:

- The process to document and maintain plant configuration and handle desired changes, while maintaining the facility safety basis and without increasing risk to personnel, facility equipment, or the environment
- The process to authorize the use of equivalent repair parts, and a method for workers to verify this approval
- The role of the CSE in CM according to DOE O 420.1B
- A method to ensure that planners and workers are familiar with the need for engineering review and approval if maintenance will not result in returning SSCs to their design configuration

Proper CM is integral to the ongoing integrity of the safety basis. Baseline configurations of SSCs that are part of the safety basis should be maintained or changes controlled to ensure they continue to support their safety function with no increase in risk to personnel, facility equipment, or the environment.

Nuclear facility maintenance is integral to configuration management in the following ways:

- Proper maintenance helps maintain consistency among design requirements, documentation, and the physical equipment.
- Proactive maintenance staves off degradation and keeps equipment operating within design requirements.
- Corrective maintenance returns SSCs to their designed/documented configuration and function.
- Work controls ensure intended changes are made and unintended changes are not introduced.
- Post-maintenance tests ensure SSCs conform to design requirements after maintenance or planned modification.
- Surveillance and testing verify continuing SSC functionality to design/safety basis requirements.

Maintenance Program Interface with Modifications

A modification is a planned and controlled change to a facility SSC that is accomplished in accordance with the requirements and limitations of applicable procedures, codes, standards, specifications, licenses, and predetermined safety restrictions identical to or commensurate with those of the item being modified. Generally, the engineering group has cognizance of the CM program. The maintenance process should address installation and verification of facility modifications based on the complexity of the task, the extent of the modification, and the importance of the equipment, just as is done for normal maintenance activities. Typically, maintenance packages, which implement a design change, have additional commissioning and/or post-installation testing requirements specified by the design change package to validate the operability of the installation.

Normal maintenance practices are intended to close out work with the affected equipment in its original baseline configuration. Replacement parts should be identical to the installed parts unless item equivalency has been reviewed and approved by engineering. The modification process addresses control of activities, which can change SSC configuration.

d. Describe the mechanisms for feedback of relevant information, such as trend analysis and instrumentation performance/reliability data, to identify necessary program modifications.

The following is taken from DOE G 433.1-1A.

A maintenance history and trending program should be implemented to document maintenance performed, to provide historical information for maintenance planning, to support maintenance and performance trending of facility systems and components, and to improve facility reliability. The documentation of complete, detailed, and usable history will be increasingly important as plant-life extension becomes an issue. Maintenance history enables trending to identify improvements for the maintenance program and needed equipment replacements or modifications. This history should assist in ensuring that root causes of failures are determined, corrected, and used in future work planning.

The maintenance history program should clearly identify the SSCs for which a history is to be maintained, the data to be collected, methods for recording data, and uses for the data. Typically, maintenance history is maintained for all SSCs for which Periodic Maintenance is performed. The program should include the type of equipment, model, serial and identification numbers, location information, and other information listed below.

As a minimum, each SSC included in the safety basis should have a separate maintenance history file. An essential element of the history files is a chronological record of the completion data of each work order including the date of completion, worker notes on completed work orders, labor hours expended, etc. The history file should include data on each review of the history including results of the review, date of review, and names of personnel who performed the review.

e. Discuss the importance of post-maintenance testing and the elements of an effective post-maintenance testing program.

The following is taken from DOE G 433.1-1A.

Post-maintenance testing requirements are clearly defined and include the following:

- Clearly written test instructions
- Test scope sufficient to verify the adequacy of work accomplished
- Test acceptance criteria

Post-maintenance testing results are documented and reviewed to ensure proper system/equipment performance before returning the system to service, and completed work-control documents are reviewed in a timely manner to check proper completion of maintenance work and to verify that corrective action resolved the problem.

26. Mechanical systems personnel shall demonstrate a working level knowledge of DOE standard DOE-STD-1073-2003, Configuration Management.

a. Describe the purpose and objectives of configuration management, emphasizing the following elements:

- **Design control**
- **Work control**
- **Change control**
- **Document control**
- **Assessment**

Design Control

The objective of the design requirements element of configuration management is to document the design requirements. The design requirements define the constraints and objectives placed on the physical and functional configuration. The design requirements to be controlled under configuration management will envelope the safety basis and, typically, the authorization basis. Consequently, proper application of the configuration management process should facilitate the contractor's efforts to maintain the safety basis and the authorization basis. Contractors must establish procedures and controls to assess new facilities and activities and modifications to facilities and activities to identify and document design requirements.

Work Control

In order to ensure that work is appropriately evaluated and coordinated before it is performed, contractors must incorporate a work control process into their procedures. Work control is an administrative process by which work activities are identified, initiated, planned, scheduled, coordinated, performed, approved, validated and reviewed for adequacy and completeness, and documented. Work control processes should ensure that when work activities are performed, consistency is maintained across the documents, the procedures, and the physical configuration of the nuclear facility.

Change Control

Contractors must establish and use a formal change control process as part of the configuration management process. The objective of change control is to maintain consistency among design requirements, the physical configuration, and the related facility documentation, even as changes are made. The change control process is used to ensure changes are properly reviewed and coordinated across the various organizations and personnel responsible for activities and programs at the nuclear facility.

Through the change control process, contractors must ensure that

- changes are identified and assessed through the change control process;
- changes receive appropriate technical and management review to evaluate the consequences of the change;
- changes are approved or disapproved;
- waivers and deviations are properly evaluated and approved or denied and the technical basis for the approval or the denial is documented;
- approved changes are adequately and fully implemented or the effects of the partial implementation are evaluated and accepted;
- implemented changes are properly assessed to ensure the results of the changes agree with the expectations; and

- documents are revised consistent with the changes and the revised documents are provided to the users.

Document Control

Document control ensures that only the most recently approved versions of documents are used in the process of operating, maintaining, and modifying the nuclear facility. Document control helps ensure that

- important facility documents are properly stored;
- revisions to documents are controlled, tracked, and completed in a timely manner;
- revised documents are formally distributed to designated users; and
- information concerning pending revisions is made available.

As controlled documents are updated to reflect changes to the requirements and/or physical installation, the contractor must ensure that

- each updated document is uniquely identified and includes a revision number and date; and
- each outdated document is replaced by the latest revision.

Assessment

The objective of assessing configuration management is to detect, document, determine the cause of, and initiate correction of inconsistencies among design requirements, documentation, and physical configuration. Properly performed assessments should help identify inconsistencies between these areas, evaluate the root causes for these problems, and prescribe improvements to avoid similar inconsistencies in the future.

b. Discuss the site-specific process for dispositioning work and change packages.

The response to this competency will vary by site. The local Qualifying Official will evaluate the completion of this element.

Mandatory Performance Activities:

Given a randomly selected mechanical system, perform the following:

- Verify adequate and comprehensive documentation exists for the system design and safety bases (e.g., technical specifications, documented safety analysis, safety evaluation report, TSRs, etc.).**
- Perform a walkdown of the system to confirm the accuracy of system drawings (P&ID/flow diagrams).**
- Review the system maintenance history.**
- Confirm that configuration management was maintained and documentation reflects any modifications.**
- Verify the adequacy of the system to perform through the full spectrum of operations, including initial system testing, required surveillance testing, and post-maintenance testing.**

- f. **Confirm knowledgeable and qualified technical personnel (system engineers, operators, and maintenance personnel) are monitoring, operating, and maintaining the system properly**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of these activities.

27. Mechanical systems personnel shall demonstrate a familiarity level knowledge of the codes and standards of the American Society for Testing and Materials (ASTM)*.

[Note: In 2001 the American Society for Testing and Materials changed its name to ASTM International.]

- a. **Discuss the general scope and subject matter range of the various ASTM codes and standards, noting those that provide relevant guidance to activities conducted at DOE defense nuclear facilities.**

The materials that make up mechanical systems are quite important for a nuclear facility. The standards mentioned below provide guidance for mechanical system design and operations at defense nuclear facilities.

ASTM A312, *Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes*, addresses the following topics related to design, construction, and/or modification of mechanical systems:

- Ordering of material
- Material and manufacturing
- Chemical composition
- Product analysis
- Tensile requirements
- Mechanical tests
- Workmanship
- Repairs

ASTM G 46, *Standard Guide for Examination and Evaluation of Pitting Corrosion*, addresses the following topics related to design, construction, and/or modification of mechanical systems:

- Identification and examination of pits
- Nondestructive examination
- Extent of pitting
- Evaluation of pitting

- b. **Describe the hierarchy of the mechanical systems rules, codes, Orders, and standards at defense nuclear facilities and explain where ASTM standards fall within that hierarchy.**

ASTM is a reference to help create the Orders and standards. The codes as identified by law are intertwined within ASTM standards and are integrated into Orders and standards used by the DOE.

c. Discuss the difference(s) between ASME material specifications and ASTM material specifications.

The following is taken from Eng-Tips Forum, ASTM A105 vs. ASME SA 105.

ASME “SA” materials are permitted for use as components for ASME pressure vessels. For example, one would expect to see SA105 carbon steel components on a vessel drawing.

ASTM “A” materials are permitted for use in power or chemical process plant piping systems that are designed to ASME B31.1 or B31.3.

d. Discuss the responsibilities of DOE as owner of facilities as defined by the standards.

The following is taken from DOE G 580.1-1.

DOE has adopted the ASTM International voluntary consensus standard for physical inventories. The standard is called E 2132-11, *Standard Practice for Inventory Verification: Electronic and Physical Inventory of Assets*. The following guidance supplements the information contained in the standard:

Procedures

The Organizational Property Management Office (OPMO) reviews and approves the DOE office and contractor physical inventory procedures and methods. Procedures that provide for a check-off from a list of property without actual verification of the physical existence and location of the property do not meet the requirements of a physical inventory and are not acceptable.

Roles

Personnel other than the property custodians complete the physical inventories unless staffing constraints or other considerations apply. In those instances, custodians may perform physical inventories as long as an independent second party verifies the results.

To the extent necessary, independent representatives, such as finance, audit, or property personnel, may observe physical inventories or conduct follow-on audits to determine if approved procedures were followed and the results are accurate. Records of these observations or audits should be retained in the inventory record file.

Reconciliations and Adjustments

Discrepancies between physical inventory results and records should be reconciled, with the records adjusted to reflect the correct quantities. A responsible official, at least one supervisory level above the supervisor in charge of the warehouse or storage facility, reviews and should approve the supporting adjustment records. An acceptable percentage of shrinkage for stores inventories should be determined by the OPMO or the property administrator on a location-by-location basis, based upon the type and cost of the materials, historical data, and other site-specific factors. The determination should be in writing and supported by appropriate documentation.

Items on an inventory adjustment report that are not within reasonable tolerances for particular items should be thoroughly investigated before the report is approved. Adjustment reports should be retained on file for inspection and review.

Reports

After reconciling the physical inventory results with the property records and financial accounts, they should be reported to the OPMO within 30 days of the reconciliation.

28. **Mechanical systems personnel shall demonstrate a working level knowledge of the codes and standards of the American Society of Mechanical Engineers.**
 - a. **Discuss the scope and subject matter of the 12 sections of the ASME Boiler and Pressure Vessel (B&PV) Code, noting relevance of the various sections to activities conducted at DOE defense nuclear facilities.**

The following is taken from *ASME Boiler and Pressure Vessel Code*, 2010 Edition.

Section I, Power Boilers

This section provides requirements for all methods of construction of power, electric, and miniature boilers; high temperature water boilers used in stationary service; and power boilers used in locomotive, portable, and traction service.

Rules pertaining to use of the V, A, M, PP, S, and E code symbol stamps are also included. The rules are applicable to boilers in which steam or other vapor is generated at pressures exceeding 15 psig, and high temperature water boilers intended for operation at pressures exceeding 160 psig and/or temperatures exceeding 250°F.

Superheaters, economizers, and other pressure parts connected directly to the boiler without intervening valves are considered as part of the scope of section I.

Section II, Materials

This volume contains four parts.

Part A, “Ferrous Materials Specifications,” is a service book to the other code sections, providing material specifications for ferrous materials adequate for safety in the field of pressure equipment.

Part B, “Nonferrous Material Specifications,” is a service book to the other code sections providing material specifications for nonferrous materials adequate for safety in the field of pressure equipment.

Part C, “Specifications for Welding Rods, Electrodes, and Filler Metal,” is a service book to the other code sections providing material specifications for manufacture, acceptability, chemical composition, mechanical usability, and more.

Part D, “Properties (Customary/Metric),” is a service book to other code sections providing tables of design stress values, tensile and yield strength values, and tables and charts of material properties.

Section III, Rules for Construction of Nuclear Power Plant Components

This section provides requirements for the materials, design, fabrication, examination, testing, inspection, installation, certification, stamping, and overpressure protection of nuclear power plant components, and component and piping supports. Components include metal vessels and systems, pumps, valves, and core support structures. The components and supports covered by this section are intended to be installed in a nuclear power system that serves the purpose of

producing and controlling the output of thermal energy from nuclear fuel and those associated systems essential to the functions and overall safety of the nuclear power system.

This section also provides requirements for 1) containment systems and transport packagings for spent fuel and high-level radioactive waste and 2) concrete reactor vessels and containments.

In addition, this section provides requirements for new construction and includes consideration of mechanical and thermal stresses due to cyclic operation. Deterioration that may occur in service as a result of radiation effects, corrosion, erosion, or instability of the material is not covered. Rules pertaining to the use of N, NPT, NA, and NV code symbol stamps are also included.

Section IV, Heating Boilers

This section provides requirements for design, fabrication, installation, and inspection of steam-generating boilers, and hot water boilers intended for low-pressure service that are directly fired by oil, gas, electricity, or coal.

It contains appendices that cover approval of new material, methods of checking safety valve and safety relief valve capacity, examples of methods of checking safety valve and safety relief valve capacity, examples of methods of calculation and computation, definitions relating to boiler design and welding, and quality control systems.

Rules pertaining to use of the H, HV, and HLW code symbol stamps are also included.

Section V, Nondestructive Examination

This section contains requirements and methods for nondestructive examination that are referenced and required by other code sections.

It also includes manufacturers' examination responsibilities, duties of authorized inspectors, and requirements for qualification of personnel, inspection, and examination.

Examination methods are intended to detect surface and internal discontinuities in materials, welds, and fabricated parts and components. A glossary of related terms is included.

Section VI, Recommended Rules for the Care and Operation of Heating Boilers

This section covers general descriptions, terminology, and operation guidelines applicable to steel and cast iron boilers limited to the operating ranges of section IV, "Heating Boilers."

It includes guidelines for associated controls and automatic fuel burning equipment. Illustrations show typical examples of available equipment. Also included is a glossary of terms commonly associated with boilers, controls, and fuel-burning equipment.

Section VII, Recommended Guidelines for the Care of Power Boilers

The purpose of these guidelines is to promote safety in the use of stationary, portable, and traction-type heating boilers.

This section provides such guidelines to assist operators of power boilers in maintaining their plants. Emphasis has been placed on industrial-type boilers because of their extensive use.

Section VIII, Division 1, Pressure Vessels

This division of section VIII provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures exceeding 15 psig.

Such pressure vessels may be fired or unfired. Specific requirements apply to several classes of material used in pressure vessel construction, and also to fabrication methods such as welding, forging, and brazing.

It contains mandatory and nonmandatory appendices detailing supplementary design criteria, nondestructive examination, and inspection acceptance standards. Rules pertaining to the use of the U, UM and UV code symbol stamps are also included.

Section VIII, Division 2, Alternative Rules

This division of section VIII provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures exceeding 15 psig. Such vessels may be fired or unfired.

This pressure may be obtained from an external source or by the application of heat from a direct or indirect source, or any combination thereof.

These rules provide an alternative to the minimum requirements for pressure vessels under division 1 rules. In comparison to the division 1 requirements, division 2 requirements on materials, design, and nondestructive examination are more rigorous; however, higher design stress intensity values are permitted.

Section VIII, Division 3, High Pressure Vessels

This division of section VIII provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures generally above 10,000 psi.

Such vessels may be fired or unfired. This pressure may be obtained from an external source, a process reaction, by the application of heat from a direct or indirect source, or any combination thereof.

Division 3 rules cover vessels intended for a specific service and installed in a fixed location or relocated from work site to work site between pressurizations.

The operation and maintenance control is retained during the useful life of the vessel by the user who prepares, or causes to be prepared, the design specifications.

Division 3 does not establish maximum pressure limits for either section VIII, divisions 1 or 2, nor minimum pressure limits for this division. Rules pertaining to the use of the UV3 code symbol stamps are also included.

Division 2 rules cover only vessels to be installed in a fixed location for a specific service where operation and maintenance control is retained during the useful life of the vessel by the user who prepares, or causes to be prepared, the design specifications.

These rules may also apply to human occupancy pressure vessels, typically in the diving industry. Rules pertaining to the use of the U2 and UV code symbol stamps are also included.

Section IX, Welding and Brazing Operations

This section contains rules relating to the qualification of welding and brazing procedures as required by other code sections for component manufacture.

It also covers rules relating to the qualification and requalification of welders, brazers, and welding and brazing operators in order that they may perform welding or brazing as required by other Code Sections in the manufacture of components.

Welding and brazing data cover essential and nonessential variables specific to the welding or brazing process used.

Section X, Fiber-Reinforced Plastic Pressure Vessels

This section provides requirements for construction of a fiber-reinforced plastic pressure vessel in conformance with a manufacturer's design report. It includes production, processing, fabrication, inspection, and testing methods required for the vessel.

Section X includes two classes of vessel design; class I, a qualification through the destructive test of a prototype, and class II, mandatory design rules and acceptance testing by nondestructive methods.

These vessels are not permitted to store, handle, or process lethal fluids. Vessel fabrication is limited to the following processes: bag-molding, centrifugal-casting and filament-winding, and contact molding. General specifications for the glass and resin materials and minimum physical properties for the composite materials are given.

Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components

This section contains division 1 and 3 in one volume, and provides rules for the examination, inservice testing and inspection, and repair and replacement of components and systems in light-water cooled and liquid-metal cooled nuclear power plants.

Application of this section of the code begins when the requirements of the construction code have been satisfied. The rules of this section constitute requirements to maintain the nuclear power plant while in operation, and to return the plant to service following plant outages and repair or replacement activities.

The rules require a mandatory program of scheduled examinations, testing, and inspections to evidence adequate safety. The method of nondestructive examination to be used, and flaw size characterization are also contained within this section.

Section XII, Rules for the Construction and Continued Service of Transport Tanks

This section covers requirements for construction and continued service of pressure vessels for the transportation of dangerous goods via highway, rail, air, or water at pressures from full vacuum to 3,000 psig and volumes greater than 120 gallons. "Construction" is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and over-pressure protection. "Continued service" is an all-inclusive term referring to inspection, testing, repair, alteration, and recertification of a transport tank that has been in service. This section also contains modal appendices containing requirements for vessels used in specific transport modes and service applications. Rules pertaining to the use of the T Code symbol stamp are also included.

- b. Discuss the ASME power piping and valve construction codes, noting the relevance of using these piping codes rather than parallel portions of the B&PV code.**

ASME B31.1, Power Piping

ASME B31.1 code prescribes minimum requirements for the design, materials, fabrication, erection, test, inspection, and maintenance of piping systems typically found in electric power generating stations, industrial institutional plants, geothermal heating systems, and central and district heating and cooling systems. The code also covers boiler external piping for power boilers and high-temperature, high-pressure water boilers in which steam or vapor is generated at a pressure of more than 15 psig; and high temperature water is generated at pressure exceeding 160 psig and/or temperatures exceeding 250°F.

ASME B31.3, Process Piping

ASME B31.3 code contains requirements for piping typically found in petroleum refineries; chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants; and related processing plants and terminals. This code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping. This code applies to piping for all fluids including: 1) raw, intermediate, and finished chemicals; 2) petroleum products; 3) gas, steam, air, and water; 4) fluidized solids; 5) refrigerants; and 6) cryogenic fluids. Also included is piping which interconnects pieces or stages within a packaged equipment assembly.

ANSI/ASME OM-2004, Code for Operation and Maintenance of Nuclear Power Plants

ANSI/ASME OM-2004 code establishes the requirements for pre-service and inservice testing and examination of certain components to assess their operational readiness in light-weight reactor power plants. It identifies the components subject to test or examination, responsibilities, methods, intervals, parameters to be measured and evaluated, criteria for evaluating the results, corrective action, personnel qualification, and record keeping. These requirements apply to a) pumps and valves that are required to perform a specific function in shutting down a reactor to the safe shutdown condition, in maintaining the safe shutdown condition, or in mitigating the consequences of an accident; b) pressure relief devices that protect systems or portions of systems that perform one or more of these three functions; and c) dynamic restraints (snubbers) used in systems that perform one or more of these three functions.

- c. Discuss the applicability of other ASME codes to defense nuclear facilities, including codes for cranes and hoists, fasteners, storage tanks, and compressors.**

According to DOE G 414.1-1B, ASME NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications* is the appropriate national standard to be used by DOE and contractor organizations for guidance on training of assessment personnel.

The following is taken from DOE G 420.1-1.

ANSI/ASME N509, *Nuclear Power Plant Air Cleaning Units and Components*, contains requirements for the design of nuclear facility air cleaning systems and ANSI/ASME N510, *Testing of Nuclear Air-Cleaning Systems*, contains requirements for testing air cleaning systems.

ASME B30.2-2005, *Overhead and Gantry Cranes—Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist*, applies to the construction, installation, operation, inspection, and

maintenance of hand-operated and power-driven overhead and gantry cranes that have a top-running single-girder or multiple-girder bridge, with one or more top-running trolley hoists used for vertical lifting and lowering of freely suspended, unguided loads consisting of equipment and materials. The requirements included in this standard also apply to cranes having the same fundamental characteristics such as cantilever gantry cranes, semi-gantry cranes, and wall cranes. Requirements for a crane used for a special purpose such as, but not limited to, non-vertical lifting service, lifting a guided load, or lifting personnel are not included in this standard.

ASME NOG-1-2004, *Rules for Construction of Overhead and Gantry Cranes*, covers top-running cranes for nuclear facilities, and ASME NUM-1 standard, *Rules for Construction of Cranes, Monorails, and Hoists*, covers the single girder, underhung, wall, and jib cranes, as well as the monorails and hoists. These two ASME nuclear crane standards provide criteria for designing, inspecting, and testing overhead handling equipment with enhanced safety to meet the defense-in-depth approach of the NRC documents NUREG 0554 *Single-Failure-Proof Cranes for Nuclear Power Plants* and NUREG 0612 *Control of Heavy Loads at Nuclear Power Plants*. In addition to providing designs for enhanced safety, the ASME nuclear crane standards provide a basis for purchasing overhead handling equipment with standard safety features, based upon accepted engineering principles, and including performance and environmental parameters specific to nuclear facilities. The ASME NOG-1 and ASME NUM-1 standards not only provide enhanced safety for handling a critical load, but also increase profit by minimizing the possibility of load drops, by reducing cumbersome operating restrictions, and by providing the foundation for a sound licensing position. The ASME nuclear crane standards can also increase profits by providing the designs and information to help ensure that the right standard equipment is purchased. Additionally, the ASME nuclear crane standards can increase profit by providing designs and information to help address current issues, such as the qualification of nuclear plant cranes for making planned engineered lifts for steam generator replacement and decommissioning.

d. Discuss the responsibilities of DOE as owner of facilities as defined by the standards.

The following is taken from DOE O 420.1B.

DOE O 420.1B establishes facility and programmatic safety requirements for both DOE and NNSA, including

- nuclear and explosive safety design criteria
- fire protection
- criticality safety
- natural phenomena hazards mitigation
- the system engineer program

In complying with DOE O 420.1B, DOE and contractors must ensure that any work done is consistent with any other safety, design, or other analysis or requirements applicable to the facility. In particular, work must be performed in accordance with the integrated safety management requirement of 48 CFR 970.5223-1, "Integration of Environment, Safety, and Health into Work Planning and Execution," and the QA requirements of either subpart A of 10 CFR 830, or DOE O 414.1D, or successor document, as applicable. All new construction, as a minimum, must comply with national consensus industry standards and the model building

codes applicable for the state or region, supplemented in a graded manner with additional safety requirements for the associated hazards in the facility that are not addressed by the codes.

29. Mechanical systems personnel shall demonstrate a familiarity level knowledge of the following organizations' non-mechanical systems-specific codes and standards:

- **American Petroleum Institute**
- **American National Standards Institute (ANSI)**
- **American Nuclear Society**
- **American Institute of Steel Construction**
- **National Fire Protection Association (NFPA)**

a. Discuss the scope and subject matter of the listed organizations' various codes, noting relevance to activities conducted at DOE defense nuclear facilities.

The following is taken from each organization's Web site.

American Petroleum Institute

The American Petroleum Institute (API) is an ANSI-accredited standards-developing organization, operating with approved standards development procedures and undergoing regular audits of its processes. API produces standards, recommended practices, specifications, codes, and technical publications, reports, and studies that cover each segment of the industry. API standards promote the use of safe, interchangeable equipment and operations through the use of proven, sound engineering practices as well as helping to reduce regulatory compliance costs. In conjunction with API's quality programs, many of these standards form the basis of API certification programs.

American National Standards Institute

As the voice of the U.S. standards and conformity assessment system, ANSI empowers its members and constituents to strengthen the U.S. marketplace position in the global economy while helping to assure the safety and health of consumers and the protection of the environment.

The Institute oversees the creation, promulgation, and use of thousands of norms and guidelines that directly impact businesses in nearly every sector, from acoustical devices to construction equipment, from dairy and livestock production to energy distribution, and many more. ANSI is also actively engaged in accrediting programs that assess conformance to standards, including globally recognized cross-sector programs such as the ISO 9000 (quality) and ISO 14000 (environmental) management systems.

American Nuclear Society

The ANS is a not-for-profit, international, scientific, and educational organization. It was established by a group of individuals who recognized the need to unify the professional activities within the diverse fields of nuclear science and technology. December 11, 1954, marks the Society's historic beginning at the National Academy of Sciences in Washington, D.C. The ANS has since developed a multifarious membership composed of approximately 11,000 engineers, scientists, administrators, and educators representing 1,600-plus corporations, educational institutions, and government agencies. It is governed by four officers and a board of directors elected by the membership.

The core purpose of the ANS is to promote the awareness and understanding of the application of nuclear science and technology.

American Institute of Steel Construction

The American Institute of Steel Construction (AISC), headquartered in Chicago, is a not-for-profit technical institute and trade association established in 1921 to serve the structural steel design community and construction industry in the United States. AISC's mission is to make structural steel the material of choice by being the leader in structural-steel-related technical and market-building activities, including specification and code development, research, education, technical assistance, quality certification, standardization, and market development. AISC has a long tradition of service to the steel construction industry, providing timely and reliable information.

National Fire Protection Association

The mission of the international nonprofit NFPA is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education. NFPA membership totals more than 81,000 individuals from around the world and more than 80 national trade and professional organizations.

Established in 1896, the NFPA serves as the world's leading advocate of fire prevention and is an authoritative source on public safety. In fact, the NFPA's 300 codes and standards influence every building, process, service, design, and installation in the United States, as well as many of those used in other countries. The NFPA's focus on true consensus has helped the association's code-development process earn accreditation from ANSI.

- 30. Mechanical systems personnel shall demonstrate a familiarity level knowledge of the codes and standards of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE).**
- a. Discuss the general scope and subject matter range of the various ASHRAE codes and standards, noting those that provide relevant guidance to activities conducted at DOE defense nuclear facilities.**

ASHRAE, founded in 1894, is an international organization of 50,000 persons. ASHRAE fulfills its mission of advancing heating, ventilation, air conditioning, and refrigeration to serve humanity and promote a sustainable world through research, standards, writings, publishing, and continued education.

ASHRAE membership includes consulting engineers, contractors, manufacturers, manufacturing representatives/sales, and architects.

- b. Discuss the responsibilities of DOE as owner of facilities as defined by the standards.**

The following is taken from DOE O 420.1B.

DOE O 420.1B establishes facility and programmatic safety requirements for both DOE and NNSA, including

- nuclear and explosive safety design criteria;
- fire protection;
- criticality safety;

- natural phenomena hazards mitigation; and
- the system engineer program.

In complying with DOE O 420.1B, DOE and contractors must ensure that any work done is consistent with any other safety, design, or other analysis or requirements applicable to the facility. In particular, work must be performed in accordance with the integrated safety management requirement of 48 CFR 970.5223-1, and the QA requirements of either subpart A of 10 CFR 830, or DOE O 414.1D, or successor document, as applicable. All new construction, as a minimum, must comply with national consensus industry standards and the model building codes applicable for the state or region, supplemented in a graded manner with additional safety requirements for the associated hazards in the facility that are not addressed by the codes.

31. Mechanical system personnel shall demonstrate a working level knowledge of the quality control inspection techniques described in sections V and XI of the ASME Boiler and Pressure Vessel code and the verification of mechanical system integrity, including:

- Ultrasonic test (UT)
- Visual inspection (VI)
- Magnetic particle test (MT)
- Dye-penetrant test (PT)
- Radiographic test (RT)
- Hydrostatic test (HT)
- Load test (LT)

a. Describe the test methodology for each of the listed test and inspection techniques, including the expected degree of accuracy.

The following information is taken from the NDT (nondestructive testing) Resource Center.

Ultrasonic Test

In an ultrasonic test, high-frequency sound waves are sent into a material by use of a transducer. The sound waves travel through the material and are received by the same transducer or a second transducer. The amount of energy transmitted or received and the time the energy is received are analyzed to determine the presence of flaws. Changes in material thickness and changes in material properties can also be measured.

Video 50. Ultrasonic test

<http://www.bing.com/videos/search?q=ultrasonic+test&view=detail&mid=3724DBDB145724B98F463724DBDB145724B98F46&first=0>

Visual Inspection

Visual inspection involves an inspector using his or her eyes to look for defects. The inspector may also use special tools such as magnifying glasses, mirrors, or borescopes to gain access to and more closely inspect the subject area. Visual examiners follow procedures that range from simple to very complex.

Magnetic Particle Test

In a magnetic particle test, a magnetic field is established in a component made from ferromagnetic material. The magnetic lines of force travel through the material and exit and reenter the material at the poles. Defects such as cracks or voids cannot support as much flux

and force some of the flux outside of the part. Magnetic particles distributed over the component will be attracted to areas of flux leakage and produce a visible indication.

Dye-Penetrant Test

In a dye-penetrant test, solution is applied to the surface of a precleaned component. The liquid is pulled into surface-breaking defects by capillary action. Excess penetrant material is carefully cleaned from the surface. A developer is applied to pull the trapped penetrant back to the surface, where it is spread out and forms an indication. The indication is much easier to see than the actual defect.

Video 51. Magnetic particle and dye-penetrant tests

<http://www.bing.com/videos/search?q=magnetic+particle+testing+video&view=detail&mid=817B6B0D9FD44C51CE53817B6B0D9FD44C51CE53&first=0>

Radiographic Test

In a radiographic test, x-rays are used with film or some other detector that is sensitive to radiation to produce images of objects. The test object is placed between the radiation source and detector. The thickness and the density of the material that x-rays must penetrate affect the amount of radiation reaching the detector. This variation in radiation produces an image on the detector that often shows internal features of the test object.

Video 52. Radiographic test

<http://www.bing.com/videos/search?q=radiographic+testing&view=detail&mid=46C5C39B3CD7BAD2C14646C5C39B3CD7BAD2C146&first=0>

Hydrostatic Test

The following is taken from Engineer's Edge, "About Hydrostatic Testing."

Hydrostatic testing is a common procedure used to verify the performance of fluid pressure vessels, such as cylinders, boilers, or tubes. Hydrostatic testing is also a common testing procedure to verify that pressure vessels do not leak or have manufacturing flaws. Hydrostatic testing is important for pressure vessels in the interest of device safety and durability under operating pressure. Hydrostatic testing is a technique to identify leaks within low-pressure vessels and devices such as pipes and plumbing.

A hydrostatic test is normally conducted under industry and/or customer requirements or specifications.

The pressure vessel to be tested is located within a sealed vessel; the sealed vessel is filled with an incompressible fluid, typically water or oil. The test vessel is then subjected to a known internal pressure for a known duration. The known internal pressure is normally a significant percent greater than the maximum operating pressure of the device. The applied pressure causes the test vessel to expand; instrumentation, which is already in place, is then read to determine the total and permanent expansion that the test chamber (external) undergoes. A physical and visual inspection then follows the hydrostatic test to determine whether the device being tested has been damaged or permanently distorted by the test pressure.

Pressure vessels may be re-verified by subjecting the vessel device to a proof-pressure test. The proof-pressure test is commonly referred to as a modified hydrostatic test. The pressure vessel is subjected to a known pressure for a predetermined time. During and following the proof-pressure test, the pressure vessel is inspected for abnormal distortion or failure.

Load Test

According to the NDT Resource Center, in a load test, a sample is put in a machine such as an Instron, and a load is applied slowly to determine the failure point of the material. This test is a simple application of pulling apart a given sample.

b. Discuss the advantages and disadvantages of each of the listed test and inspection techniques.

The following is taken from the NDT (nondestructive testing) Resource Center.

Ultrasonic Test

ADVANTAGES

- depth of penetration for flaw detection or measurement is superior to other methods
- only single-sided access is required
- provides distance information
- minimum part preparation is required
- method can be used for much more than just flaw detection

DISADVANTAGES

- surface must be accessible to probe and couplant
- skill and training required is more extensive than other techniques
- surface finish and roughness can interfere with inspection
- thin parts may be difficult to inspect
- linear defects oriented parallel to the sound beam can go undetected
- reference standards are often needed

Visual Inspection

ADVANTAGES

- inexpensive
- highly portable
- minimum training
- immediate results
- minimum part preparation

DISADVANTAGES

- surface discontinuities
- misinterpretation of scratches

Magnetic Particle Test

ADVANTAGES

- large surface areas of complex parts can be inspected rapidly
- can detect surface and subsurface flaws
- surface preparation is less critical than it is in penetrant inspection
- magnetic particle indications are produced directly on the surface of the part and form an image of the discontinuity
- equipment costs are relatively low

DISADVANTAGES

- only ferromagnetic materials can be inspected
- proper alignment of magnetic field and defect is critical
- large currents are needed for very large parts
- requires relatively smooth surface
- paint or other nonmagnetic coverings adversely affect sensitivity
- demagnetization and post-test cleaning is usually necessary

Dye-Penetrant Test

ADVANTAGES

- large surface areas or large volumes of parts/materials can be inspected rapidly and at low cost
- parts with complex geometry are routinely inspected
- indications are produced directly on surface of the part, providing a visual image of the discontinuity
- equipment investment is minimal

DISADVANTAGES

- detects only surface breaking defects
- surface preparation is critical as contaminants can mask defects
- requires a relatively smooth and nonporous surface
- post-test cleaning is necessary to remove chemicals
- requires multiple operations under controlled conditions
- chemical handling precautions are necessary (toxicity, fire, waste)

Radiographic Test

ADVANTAGES

- can be used to inspect virtually all materials
- detects surface and subsurface defects
- ability to inspect complex shapes and multi-layered structures without disassembly
- minimum part preparation is required

DISADVANTAGES

- extensive operator training and skill required
- access to both sides of the structure is usually required
- orientation of the radiation beam to non-volumetric defects is critical
- field inspection of thick section can be time consuming
- relatively expensive equipment investment is required
- possible radiation hazard for personnel

Hydrostatic Test

ADVANTAGES

- simple and thorough process

DISADVANTAGES

- needs to be performed on a closed system or component.
- may cause damage to system

Load Test

ADVANTAGES

- identifies the failure point of material

DISADVANTAGES

- destructive test that renders the component useless

c. Identify and describe the usual application for each of the listed test and inspection techniques.

The following is taken from the NDT (nondestructive testing) Resource Center.

Ultrasonic Test

Ultrasonic tests, based on sound velocity and attenuation measurements, are used to locate surface and subsurface defects in many materials, including metals, plastics, and wood. Ultrasonic inspection is also used to measure the thickness of materials and otherwise characterize properties of materials.

Visual Inspection

A visual examination can be used to check for obvious problem areas, such as leaks, excess vibration, or misalignment. It can also be used to check for corrosion on exposed metal surfaces. Specific guidance on the inspection of pressure vessels for corrosion and other flaws is given in API Recommended Practice 572, *Inspection of Pressure Vessels*, and on the inspection of piping, valves, and fittings associated with pressure vessels in API Recommended Practice 574, *Inspection Practices for Piping System Components*.

Magnetic Particle Test

Magnetic particle tests are used to inspect ferromagnetic materials (those that can be magnetized) for defects that result in a transition in the magnetic permeability of a material. Magnetic particle inspection can detect surface and near surface defects.

Dye-Penetrant Test

Penetrant tests are used to locate cracks, porosity, and other defects that break the surface of a material and have enough volume to trap and hold the penetrant material. Liquid penetrant testing is used to inspect large areas very efficiently and will work on most nonporous materials.

Radiographic Test

Radiographic tests are used to inspect almost any material for surface and subsurface defects. X-rays can also be used to locate and measure internal features, to confirm the location of hidden parts in an assembly, and to measure the thickness of materials.

Hydrostatic Test

Hydrostatic testing is a common procedure used to verify the performance of a fluid pressure vessel, such as cylinders, boilers, or tubes. Hydrostatic testing is also a common testing procedure to verify that pressure vessels do not leak or have manufacturing flaws.

Load Test

Load testing is a destructive test that will render the test component useless for any application. The load test finds the tensile or compressive stress at which a material fails. This is usually done on a test sample and not on a system component. This test is valuable in determining whether the material the system is built with will withstand design specifications of stress.

- d. For each of the listed test and inspection techniques, identify and discuss the safety considerations and precautions that must be observed.**

Ultrasonic Test

The following is taken from Health and Safety Executive, *Hazards Arising from Ultrasonic Processes*.

To date, some types of industrial plants using ultrasonic frequencies have been found to produce sound in the audible range from 96–105 dB(A) (decibel, A weighted), although it may not appear noisy to older persons and those with imperfect hearing. The World Health Organization has proposed the following maximum exposure levels for unprotected persons: 75 dB for frequencies from 14.1 kilohertz (kHz) and 110 dB for frequencies greater than 22.5 kHz.

Where reasonably practicable, excessive noise levels should be reduced. Usually this will be by enclosures, and thin layers of common material will give adequate acoustic insulation at upper audible frequencies. Alternatively, ear protectors can be provided and used. Although the attenuation afforded by protectors is usually only measured up to 8 kHz, it is likely that attenuation at frequencies higher than this will be at least as great as at 8 kHz.

If fingers or hands are put into an ultrasonic cleaning bath, a tickling sensation is instantly experienced on the skin surface followed 2–3 seconds later by pain in the joints. The hazards are likely to be well known to those involved, but notices warning of these hazards may be appropriate and baskets or racks should be used at baths.

Some scientists have asserted that effects such as nausea, dizziness, tiredness, and tinnitus can be caused by exposure to sound in the ultrasonic frequencies and others have asserted that the upper audible frequencies are also implicated. Some countries have established exposure limits for the ultrasonic frequencies.

Visual Inspection

Visual inspection adds no significant risk to persons performing the inspection beyond risk that may exist for the system or facility in its current condition.

Magnetic Particle Test

The following is taken from NASA Engineering Network, “Magnetic Particle Testing of Aerospace Materials.”

The safe handling of magnetic particles is governed by the suppliers’ MSDS. A supplier’s MSDS should certify that the flash point of the oil carriers meet the requirements of DOD-F-87935, *Fluid, Magnetic Particle Inspection, Suspension Medium*. The MSDS should also detail personnel hazards such as inhalation, skin contact, and eye exposure. Magnetizing equipment should be properly maintained to avoid personnel hazards from electrical shorts. Care should also be taken to avoid electrical arcing and possible ignition of the oil carriers. Any broken ultraviolet filters or bulbs should be replaced immediately. Personnel entering a darkened area

to perform fluorescent testing should wait at least 1 minute for their eyes to adjust to the darkened area.

Dye-Penetrant Test

The following is taken from NASA, “Penetrant Testing of Aerospace Materials.”

The hazardous properties that should always be considered when using a dye penetrant are liquid flashpoint and toxicity. The flashpoint of penetrant processes can be as low as 40°F to as high as 200°F. The penetrants should be used per manufacturers’ instructions. Most penetrants are not actually toxic and do not present a particular hazard in normal use. However, there are precautions that should be followed. Practically all liquid materials used in penetrant, cleaner, and developer have good wetting and detergent properties. Therefore, they exhibit excellent solvent power for fats and oils. These materials, when allowed to contact the skin for an extended period, will dry out the natural oils from the skin, causing it to become rough, red, and if left untreated, to eventually crack open, which could cause a severe secondary infection. This is preventable by wearing neoprene-type gloves and apron, a face shield, and protective clothing. If exposed to this skin drying, replenishing the oils on the exposed skin should prevent any cracking.

Radiographic Test

According to the *Guide to European Pressure Equipment*, x-rays and gamma rays are very hazardous. Special precautions must be taken when performing radiography. Therefore, the method is undertaken under controlled conditions, inside a protective enclosure, or after assessment, with appropriate barriers and warning systems to ensure that there are no hazards to personnel. DOE facilities will usually have a safety analysis in place for use with the equipment, or the equipment will have certain safety constraints in place. Personnel handling the radiography machine will have ample training and know the functions of the equipment.

Hydrostatic Test

According to DOE-HDBK-1017/1-93, during hydrostatic testing, minimum pressurization temperature precautions include making sure that the desired hydrostatic pressure is consistent with plant temperatures so that excessive stress does not occur.

Load Test

Load testing uses a machine at high pressures. This machine should be well maintained to prevent any possible accidents. The operator should wear goggles and understand the operation of the machine. Personnel should keep a safe distance from equipment during use.

e. Identify the special hazards that are associated with radiographic testing and discuss how they are mitigated.

The following is taken from NASA, “Radiographic Testing of Aerospace Materials.”

Radiography constitutes a health hazard that requires special radiation training for personnel involved with its use. Also, adequate safety devices should be built into the x-ray facility, including

- safety interlock switches
- keylock system
- radiation monitoring device

- warning system
- adequate facility shielding

At least one qualified operator plus a radiation protection supervisor or designated alternate must be present at all times during any x-ray operation. The personnel requiring access to the x-ray area must be monitored to ensure that no one absorbs excessive amounts of radiation. The normal means for monitoring radiation is to wear pocket dosimeters and film badges. The dosimeter is read and recorded daily and usually the film badge is developed and read at least quarterly. Both devices are compared and should check within 20 percent of each other. The allowable dose of radiation is 1.25 roentgen equivalent man (rem) per quarter year. For added safety, each time the x-ray area is entered a survey meter should be used to ensure that the area is safe to enter.

Interpretation of radiographs requires highly trained and qualified technicians who must 1) define the quality of the radiographic image, which requires a critical analysis of the radiographic procedure and the image developing procedure; 2) analyze the image to determine the nature and extent of any abnormal condition in the test piece; 3) evaluate the test piece by comparing interpreted information with standards or specifications; and (4) report inspection results accurately and clearly.

f. Identify the special qualifications needed by technicians performing each of the listed test and inspection techniques and discuss how those qualifications are achieved.

The following is taken from the NDT (nondestructive testing) Resource Center.

Nondestructive testing personnel are often certified by their employer or other agency to meet certain qualifications, which are established by industry. Certification is basically a process of providing written testimony that an individual is qualified to do certain work. The qualifications of an individual are based on education, level of training, work experience, and the ability to pass a vision test. In the field of nondestructive testing, certification is very important because nondestructive testing personnel are often making critical judgments that can have safety and/or significant financial consequences. Nondestructive testing personnel must have a great deal of confidence in the results of their work. Since many of the nondestructive testing methods do not produce a record of the inspection results, certification presents objective evidence of the knowledge and skill level of the individual performing an inspection.

The procedure used to assure that nondestructive testing personnel possess the qualifications necessary to do competent work includes

- training to gain the necessary knowledge
- experience under the guidance of knowledgeable people
- qualification examinations to demonstrate that competency has been achieved
- certification to document successful demonstration of competency
- There are a number of organizations that have produced documents that recommend or specify the minimum qualifications for certification. The following is a partial list of documents pertaining to the certification of nondestructive testing personnel in the U.S.:
 - *American Society for Nondestructive Testing, Recommended Practice No. SNT-TC-1A, Non-Destructive Testing*

- Aviation Transport Association, ATA-105, *Guidelines for Training and Qualifying Personnel in Nondestructive Testing Methods*
- Aerospace Industries Association, AIA-NAS-410, National Aerospace Standard, *NAS Certification and Qualification of Nondestructive Test Personnel*
- International Organization for Standards, ISO 9712, *Nondestructive Testing — Qualification and Certification of Personnel*

The education and work experience requirements for the various specifications are common or similar. Typical requirements are summarized in table 3 for qualification levels I and II.

Table 3. Nondestructive testing personnel training requirements

Examination Method	Level	Required Nondestructive-Testing Training (Hrs ^b) with—		Work Experience (Min Hrs ^d)	Time to Obtain Work Experience (Mo ^e)
		HS ^b diploma or equivalent	2 yrs college or technical school ^f		
Acoustic emission	I	40	32	210	1.5 – 9
	II	40	40	630	4.5 – 27
Electromagnetic	I	40	24	210	1.5 – 9
	II	40	40	630	4.5 – 27
Liquid penetrant	I	4	4	70	0.5 – 3
	II	8	4	140	1 – 6
Magnetic particle	I	12	8	70	0.5 – 3
	II	8	4	210	1.5 – 9
Neutron radiography	I	28	20	420	3 – 18
	II	40	40	1,680	12 – 72
Radiography	I	40	30	210	1.5 – 9
	II	40	35	630	4.5 – 27
Thermal/infrared	I	32	30	210	1.5 – 9
	II	34	32	1,260	9 – 27
Ultrasonic	I	40	30	210	1.5 – 9
	II	40	40	840	4.5 – 27
Vibration analysis	I	24	24	420	2 – 18
	II	72	48	1,680	12 – 72
Visual	I	8	4	70	0.5 – 3
	II	16	8	140	1 – 6

Notes:

^aHrs – hours ^cMinimum of 2 years engineering or science study ^eMo – months

^bHS – high school ^dMin Hrs – minimum hours of required work experience in a method

Source: Data from the NDT (nondestructive testing) Resource Center

Nondestructive testing training can be obtained at colleges, at vocational-technical schools, through the Armed Forces, from commercial training companies, and through individual company training departments.

To be considered for certification at level III, an individual must have

- graduated from a university or college, with a degree in engineering or science, and have at least 1 year of experience comparable to that of level II in the applicable nondestructive testing method(s);

- completed with passing grades at least 2 years of engineering or science study at a university, college, or technical school, and have 2 years of experience comparable to that of level II in the applicable nondestructive testing method(s);
- 4 years of experience comparable to that of level II in the applicable nondestructive testing method(s).

Mandatory Performance Activities:

- a. **Given system specifications, including a system diagram, determine the key information for a hydrostatic test on that system.**
- b. **Given a work package, determine the appropriate tests needed to ensure proper installation of the mechanical system.**
- c. **Given component information, describe the load tests required prior to lifting that component.**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of these activities.

MANAGEMENT, ASSESSMENT, AND OVERSIGHT

32. **Mechanical systems personnel shall demonstrate a working level knowledge of problem analysis principles and the ability to apply techniques necessary to identify problems, determine potential causes of problems, and identify corrective action(s).**
 - a. **Describe and explain the application of problem analysis techniques, including the following:**
 - **Root cause analysis**
 - **Causal factor analysis**
 - **Change analysis**
 - **Barrier analysis**
 - **Management oversight risk tree (MORT) analysis**

Root Cause Analysis

The following is taken from Wikipedia, “Root Cause Analysis.”

Root cause analysis (RCA) is a class of problem solving methods aimed at identifying the root causes of problems or events.

Root cause analysis is any structured approach to identifying the factors that resulted in the nature, the magnitude, the location, and the timing of the harmful outcomes of one or more past events to identify what behaviors, actions, inactions, or conditions need to be changed to prevent recurrence of similar harmful outcomes and to identify the lessons to be learned to promote the achievement of better consequences.

The practice of RCA is predicated on the belief that problems are best solved by attempting to address, correct, or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. By directing corrective measures at root causes, it is more probable that problem recurrence will be prevented. However, it is recognized that complete prevention of recurrence by one corrective action is not always possible.

Nevertheless, in the U.S. nuclear power industry, the NRC requires that in the case of significant conditions adverse to quality, the measures shall assure that the cause of the condition is determined and corrective action taken to prevent repetition. In practice, more than one cause is allowed and more than one corrective action is not forbidden.

Conversely, there may be several effective measures that address the root causes of a problem. Thus, RCA is often considered to be an iterative process, and is frequently viewed as a tool of continuous improvement.

RCA is typically used as a reactive method of identifying event(s) causes, revealing problems and solving them. Analysis is done after an event has occurred. Insights in RCA may make it useful as a pro-active method. In that event, RCA can be used to forecast or predict probable events even before they occur.

Root cause analysis is not a single, sharply defined methodology; there are many different tools, processes, and philosophies for performing RCA. However, several very-broadly defined approaches or schools can be identified by their basic approach or field of origin: safety-based, production-based, process-based, failure-based, and systems-based.

- Safety-based RCA descends from the fields of accident analysis and occupational safety and health.
- Production-based RCA has its origins in the field of quality control for industrial manufacturing.
- Process-based RCA is basically a follow-on to production-based RCA, but with a scope that has been expanded to include business processes.
- Failure-based RCA is rooted in the practice of failure analysis as employed in engineering and maintenance.
- Systems-based RCA has emerged as an amalgamation of the preceding schools, along with ideas taken from fields such as change management, risk management, and systems analysis.

Despite the different approaches among the various schools of root cause analysis, there are some common principles. It is also possible to define several general processes for performing RCA.

GENERAL PRINCIPLES OF ROOT CAUSE ANALYSIS

The primary aim of RCA is to identify the factors that resulted in the nature, the magnitude, the location, and the timing of the harmful outcomes of one or more past events to identify what behaviors, actions, inactions, or conditions need to be changed to prevent recurrence of similar harmful outcomes and to identify the lessons to be learned to promote the achievement of better consequences.

To be effective, RCA must be performed systematically, usually as part of an investigation, with conclusions and root causes identified and backed up by documented evidence. Usually a team effort is required.

There may be more than one root cause for an event or a problem, the difficult part is demonstrating the persistence and sustaining the effort required to develop them.

The purpose of identifying all solutions to a problem is to prevent recurrence at the lowest cost and in the simplest way. If there are alternatives that are equally effective, then the simplest or lowest cost approach is preferred.

Root causes identified depend on the way in which the problem or event is defined. Effective problem statements and event descriptions are helpful, or even required.

To be effective, the analysis should establish a sequence of events or timeline to understand the relationships between contributory factors, root cause(s), and the defined problem or event to prevent it in the future.

Root cause analysis can help to transform a reactive culture into a forward-looking culture that solves problems before they occur or escalate. More importantly, it reduces the frequency of problems occurring over time within the environment where the RCA process is used.

RCA is a threat to many cultures and environments. Threats to cultures often meet with resistance. There may be other forms of management support required to achieve RCA effectiveness and success. For example, a non-punitive policy towards problem identifiers may be required.

GENERAL PROCESS FOR PERFORMING AND DOCUMENTING AN RCA-BASED CORRECTIVE ACTION

Notice that RCA (in steps 3, 4, and 5) forms the most critical part of successful corrective action, because it directs the corrective action at the true root cause of the problem. The root cause is secondary to the goal of prevention, but without knowing the root cause, it is not possible to determine what an effective corrective action for the defined problem will be.

1. Define the problem or describe the event factually. Include the qualitative and quantitative attributes of the harmful outcomes. This usually includes specifying the natures, the magnitudes, the locations, and the timings.
2. Gather data and evidence, classifying that along a timeline of events to the final failure or crisis. For every behavior, condition, action, and inaction specify in the timeline what should have been when it differs from the actual.
3. Ask why and identify the causes associated with each step in the sequence towards the defined problem or event. Why is taken to mean, "What were the factors that directly resulted in the effect?"
4. Classify causes into causal factors that relate to an event in the sequence, and root causes, that if eliminated can be agreed to have interrupted that step of the sequence chain.
5. Identify all other harmful factors that have equal or better claim to be called root causes. If there are multiple root causes, which is often the case, reveal those clearly for later optimum selection.
6. Identify corrective action(s) that will with certainty prevent recurrence of each harmful effect, including outcomes and factors. Check that each corrective action would, if pre-implemented before the event, have reduced or prevented specific harmful effects.
7. Identify solutions that, when effective, prevent recurrence with reasonable certainty with consensus agreement of the group, are within your control, meet your goals and objectives, and do not cause or introduce other new, unforeseen problems.
8. Implement the recommended root cause correction(s).
9. Ensure effectiveness by observing the implemented recommendation solutions.

10. Identify other methodologies for problem solving and problem avoidance that may be useful.
11. Identify and address the other instances of each harmful outcome and harmful factor.

Video 53. Root cause analysis

<http://vimeo.com/35011862>

Causal Factor Analysis

The following is taken from the OSHAcademy, “Event and Causal Factor Analysis.”

Event and causal factor charting is a written or graphical description for the time sequence of contributing events associated with an accident. The charts produced in event charting consist of the following elements:

Condition—A distinct state that facilitates the occurrence of an event. A condition may be equipment status, weather, employee health, or anything that affects an event.

Event—A point in time defined by a specific action occurring.

Accident—Any action, state, or condition in which a system is not meeting one or more of its design intents. Includes actual accidents and near misses. This event is the focus of the analysis.

Primary event line—The key sequence of occurrences that led to the accident. The primary event line provides the basic nature of the event in a logical progression, but it does not provide all of the contributing causes. This line always contains the accident, but it does not necessarily end with an accident event. The primary event line can contain both events and conditions.

Primary events and conditions—The events and conditions that make up the primary event line.

Secondary event lines—The sequences of occurrences that lead to primary events or primary conditions. The secondary event lines expand the development of the primary event line to show all of the contributing causes for an accident. Causal factors are almost always found in secondary event lines, and most event and causal factor charts have more than one secondary event line. Note that the secondary event lines can contain both events and conditions.

Secondary events and conditions—The events and conditions that make up a secondary event line.

Causal factors—Key events or conditions that, if eliminated, would have prevented an accident or reduced its effects. Causal factors are such things as human error or equipment failure, and they commonly include the following:

- The initiating event for an accident
- Each failed safeguard
- Each reasonable safeguard that was not provided

Items of note—Undesirable events or conditions identified during an analysis that must be addressed or corrected but did not contribute to the accident of interest. These are shown as separate boxes outside the event chain.

Although event charting is an effective tool for understanding the sequence of contributing events that lead to an accident, it does have two primary limitations:

- ## PROCEDURE FOR EVENT AND CAUSAL FACTOR CHARTING



Figure 89. Event and causal factor procedure

1. Gather and organize data. Collect known data for actors associated with the accident. An actor is a person, parameter, or object that has an action in the event chain. Organize the data into a timeline. Review data for consistency and gaps. This step is not always necessary for simple events.
2. Select the accident. Define the accident of interest. If there is more than one accident, choose the last one to occur.
3. Define the primary sequence of events leading to the accident. Outline the thumbnail sketch of the sequence of events leading to the accident. Work backward from the accident, making certain that each subsequent event is the one that most directly leads to the previous event. Draw events as rectangles
 - describe events specifically with one noun and one action verb
 - use quantitative descriptions when possible to characterize events
 - include the timing of the event when known
 - use solid lines for known events and dashed lines for assumed events

Draw conditions as ovals

- describe conditions specifically using a form of the verb to be
 - use quantitative descriptions to characterize conditions
 - include the timing and duration of the condition when known
 - use solid lines for known conditions and dashed lines for assumed conditions
4. Complete the model by adding secondary events and conditions. Add secondary events and conditions as appropriate to ensure that all events and conditions leading to an accident are sufficient and necessary to cause the accident. Add events as appropriate to display the contributors to the secondary events and conditions.
 5. Identify causal factors and items of note. Designate the underlying contributors to the accident as causal factors. Document any items of note.

Video 54. Causal factor analysis

<http://www.bing.com/videos/search?q=causal+factor+analysis&view=detail&mid=688B9B1584793737F29D688B9B1584793737F29D&first=0>

Change Analysis

The following is taken from Bill-Wilson, “Change Analysis.”

Change analysis is an investigation technique that involves the precise specification of a single deviation so that changes and/or differences leading to the deviation may be found by comparison to similar situations in which no deviation occurred.

As suggested by the name of the technique, change analysis is based on the concept that change (or difference) can lead to deviations in performance. This presupposes that a suitable basis for comparison exists. What is then required is to fully specify both the deviated and undeviated conditions, and then compare the two so that changes or differences can be identified. Any change identified in this process thus becomes a candidate cause of the overall deviation.

There are basically three types of situations that can be used. First, if the deviation occurred during performance of some task or operation that has been performed before, then this past experience can be the basis. Second, if there is some other task or operation that is similar to the deviated situation, then that can be used. Finally, a detailed model or simulation of the task can be used, if feasible.

Once a suitable basis for comparison is identified, then the deviation can be specified. Various schemes exist for performing this specification. Perhaps the most useful scheme involves four dimensions (WHAT, WHERE, WHEN, and EXTENT) and two aspects (IS and IS NOT). Regardless of the scheme used, the end result should be a list of characteristics that fully describe the deviated condition.

Given the full specification of the deviated condition, it becomes possible to perform a detailed comparison with the selected undeviated condition. Each difference between the deviated and undeviated situations is marked for further investigation. In essence, each individual difference is a potential cause of the overall deviation.

After the potential causes are found, each is reviewed to determine if it could reasonably lead to the deviation, and under what circumstances. The most likely causes are those that require the fewest additional conditions or assumptions. In this way, a large list of potential causes can be

whittled down to a short list of likely causes. Finally, given the likely causes, the actual or true cause(s) must be identified. Generally speaking, the only way to verify which likely cause is the true cause is by testing.

The purpose of change analysis is to discover likely causes of a deviation through comparison with a non-deviated condition, and then to verify true causes by testing. True causes found using change analysis are usually direct causes of a single deviation; change analysis will not usually yield root causes. However, change analysis may at times be the only method that can find important, direct causes that are obscure or hidden. Success in change analysis depends ultimately on the precision used to specify a deviation, and in verification of true cause through testing.

Change analysis is heavily dependent on comparison with similar situations. However, there are varying degrees of similarity, depending on how close the undeviated condition is to the deviation under investigation. The best case scenario for change analysis includes access to previous operational history for the exact same task or operation. In this case, changes or differences that could have contributed to the deviation are easily identifiable.

The problem with trying to compare situations that are less similar is that other, inherent differences in underlying conditions may mask differences that were responsible for the deviation. Since each difference identified in the change analysis procedure is considered a potential cause, the list of potential causes may include some of these inherent differences that may or may not bear any causal relation to the specific deviation under investigation.

It is therefore critical that an appropriate basis for comparison be selected when performing change analysis. Furthermore, inherent differences between the actual deviated condition and the situation chosen for comparison must be fully identified and handled with extreme care. Finally, when verifying true cause by testing, the test condition must be made as identical to the actual deviated condition as possible.

Barrier Analysis

The following is taken from Bill-Wilson, “Barrier Analysis.”

Barrier analysis is an investigation or design method that involves the tracing of pathways by which a target is adversely affected by a hazard, including the identification of any failed or missing countermeasures that could or should have prevented the undesired effect(s).

At the heart of barrier analysis is the concept of the target. The primary quality of a target is that it exists under a specified range or set of conditions, and that it is maintained within that specified range or set of conditions. This very general quality means that almost anything can be a target—a person, a piece of equipment, a collection of data, etc.

Given the concept of the target, the means by which a target is adversely affected is investigated. The term adverse effect means that the target is somehow moved outside of its required range or set of conditions. Anything that does this is called a hazard. This is a very general quality—almost anything can be a hazard. However, it is possible to uniquely define hazard/target pairs by the pathways through which hazards affects targets.

Having identified hazards, targets, and the pathways through which hazards affect targets, the concepts of barriers and controls are discovered. These are used to protect and/or maintain a target within its specified range or set of conditions, despite the presence of hazards. The

primary quality of a barrier or control is that it cuts off a pathway by which a hazard can affect a target.

Barriers and controls are often designed into systems, or planned into activities, to protect people, equipment, information, etc. The problem is that design and planning are rarely perfect. All hazards may not be identified beforehand, or unrecognized pathways to targets may surface. In both of these cases, appropriate barriers and controls may not be present. Even if they are present, they may not be as effective as originally intended. As a result, targets may lack adequate protection from change or damage.

The purpose of barrier analysis is to identify pathways that were left unprotected, or barriers and controls that were present but not effective. All pathways relate to specific hazard/target pairs, and all barriers and controls relate to specific pathways. Success in barrier analysis depends on the complete and thorough identification of all pathways.

Management Oversight Risk Tree (MORT) Analysis

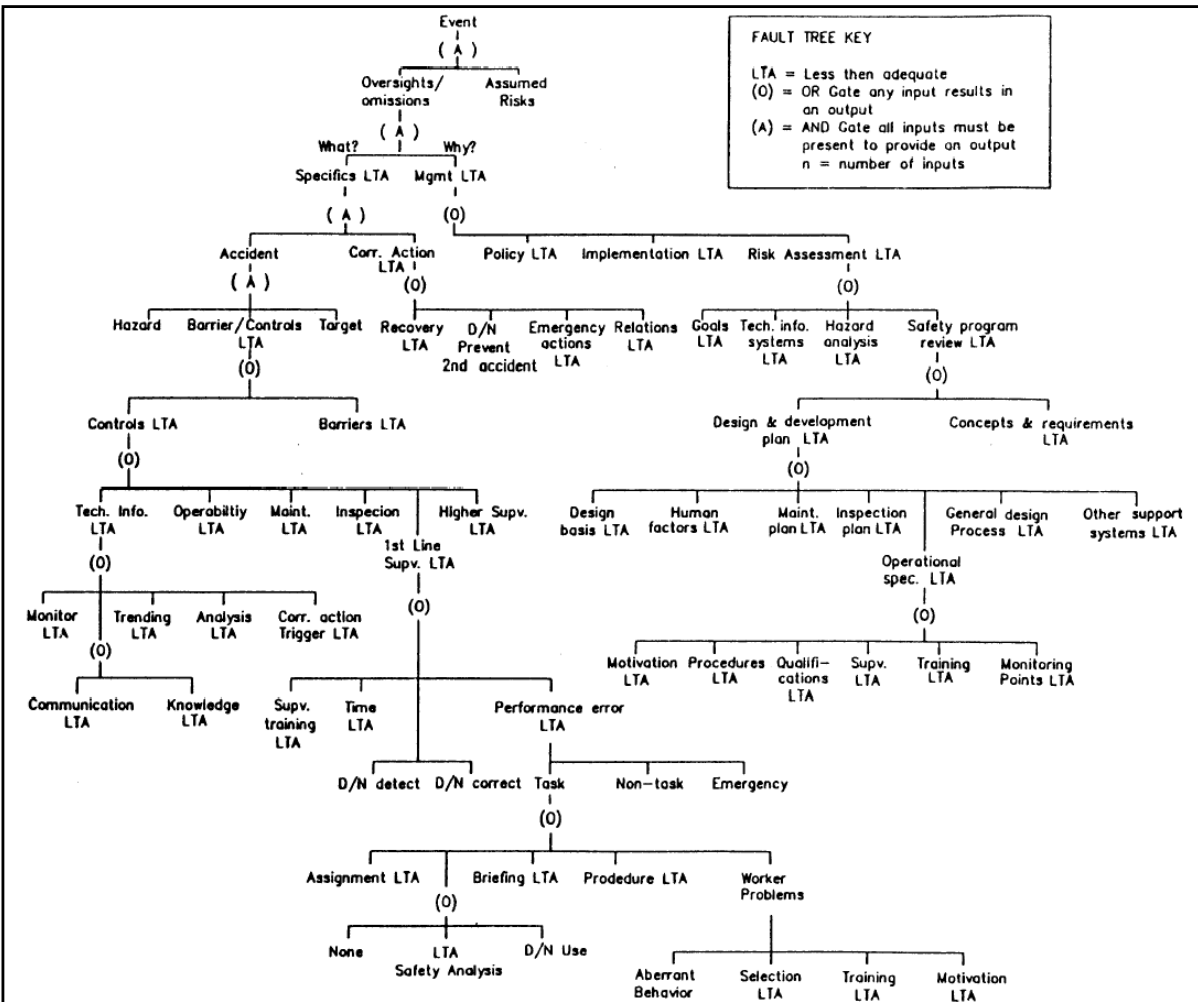
The following is taken from DOE-NE-STD-1004-92 (archived).

MORT/mini-MORT is used to prevent oversights in the identification of causal factors. The left side of the tree lists specific factors relating to the occurrence, and the right side of the tree lists the management deficiencies that permit specific factors to exist. The management factors all support each of the specific barrier/control factors. Included is a set of questions to be asked for each of the factors on the tree. It is useful in preventing oversights and ensuring that all potential causal factors are considered. It is especially useful when there is a shortage of experts to ask the right questions.

However, because each of the management factors may apply to the specific barrier/control factors, the direct linkage or relationship is not shown but is left up to the analyst. For this reason, events and causal factor analysis and MORT should be used together for serious occurrences: one to show the relationship, the other to prevent oversights. A number of condensed versions of MORT, called mini-MORT, have been produced. For a major occurrence justifying a comprehensive investigation, a full MORT analysis could be performed while mini-MORT would be used for most other occurrences.

A mini-MORT analysis chart is shown in figure 90. This chart is a “checklist” of what happened (less than-adequate [LTA] specific barriers and controls) and why it happened (LTA management). To perform the MORT analysis, perform the following:

- Identify the problem associated with the occurrence and list it as the top event.
- Identify the elements on the “what” side of the tree that describe what happened in the occurrence (what barrier or control problems existed).
- Identify the management elements on the “why” side of the tree that permitted the barrier control problem for each barrier or control problem.
- Describe each of the identified inadequate elements (problems) and summarize the findings.



Source: DOE-NE-STD-1004-92

Figure 90. Mini-MORT analysis chart

These findings can then be related to the ORPS cause codes. For critical self-assessment, the findings can also be related to MORT elements given in figure 91. To do this, enter the findings in the left-hand column. Next, select the MORT elements from the top of the root cause form that most closely relate to the finding by placing a check in the column below the MORT elements and on the same line where the finding is listed. Then, sum the number of checks under each MORT element. The relative number of checks under each MORT element is a measure of how widespread the inadequacy is. The results guide the specific and generic corrective actions.

MORT BASED ROOT CAUSE ANALYSIS FORM																															
Management																															
Policy	Policy Implementation						Risk Assessment						Bridge Elements			Specific Factors						Task Performance									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
	Policy	Self Responsibility	Accountability	Vigor/Example	Methods/Critical Analysis	Open	Technical Info. Systems	Hazard Analysis Process	Program Review	Management Service	Open	Directive	Budget	Information Flow	Open	Open	Open	Technical Information	Operational Readiness	Maintenance	Inspection	Supervision	Open	Open	Open	Open	Open	Open	Open	Open	
Findings or Conclusions																															

Source: DOE-NE-STD-1004-92

Figure 91. MORT-based root cause analysis form

A brief explanation of the “what” and “why” may assist in using mini-MORT for causal analyses.

When a target inadvertently comes in contact with a hazard and sustains damage, the event is an accident. A hazard is any condition, situation, or activity representing a potential for adversely affecting economic values or the health or quality of people’s lives. A target can be any process, hardware, person, the environment, product quality, or schedule—anything that has economic or personal value.

What prevents accidents or adverse programmatic impact events?

- Barriers that surround the hazard and/or the target and prevent contact, or controls and procedures that ensure separation of the hazard from the target
- Plans and procedures that avoid conflicting conditions and prevent programmatic impacts

In a facility, what functions implement and maintain these barriers, controls, plans, and procedures?

- Identifying the hazards, targets, and potential contacts or interactions and specifying the barriers/controls that minimize the likelihood and consequences of these contacts
- Identifying potential conflicts/problems in areas such as operations, scheduling, or quality and specifying management policy, plans, and programs that minimize the likelihood and consequences of these adverse occurrences
- Providing the physical barriers: designing, installation, signs/warnings, training, or procedures
- Providing planning/scheduling, administrative controls, resources, or constraints
- Verifying that the barriers/controls have been implemented and are being maintained by operational readiness, inspections, audits, maintenance, and configuration/change control
- Verifying that planning, scheduling, and administrative controls have been implemented and are adequate
- Policy and policy implementation

b. Describe and explain the application of the following root cause analysis processes in the performance of occurrence investigations:

- **Event and causal factors charting**
- **Root cause coding**
- **Recommendation generation**

Event and Causal Factors Charting

Refer to 32a for a description of event and causal factors charting.

Root Cause Coding

According to DOE O 232.2, *Occurrence Reporting and Processing of Operations Information*, causes must be identified and appropriately documented according to the causal analysis tree, which is available in DOE O 232.2, attachment 5. The “Description of Cause” field must include a brief discussion that clearly links the event to the cause code(s) and resulting corrective actions.

Recommendation Generation

The following is taken from *Root Cause Analysis Handbook: A Guide to Efficient and Effective Incident Investigation* by James Rooney, et al:

Perhaps the most significant aspect of root cause analysis is the final step. Following the identification of root cause(s) for a particular causal factor, recommendations for preventing recurrence must be generated. The identification of effective corrective actions is addressed explicitly in the definition of root causes. Root causes are defined as the most basic causes that can reasonably be identified, which management has control to fix, and for which effective recommendations for preventing recurrence can be generated. The emphasis is on correcting the problem so that it will not be repeated. The following criteria for ensuring the viability of corrective actions are suggested:

- Will these corrective actions prevent recurrence of the condition or event?
- Is the corrective action within the capability of the organization to implement?
- Are the recommendations directly related to the root causes?
- Is it possible to ensure that implementation of the recommendation will not introduce unacceptable risks?

The corrective actions developed should address not only the specific circumstances of the event that occurred, but also system improvements aimed at the incident’s root causes. They should address options for reducing the frequency, minimizing the personnel exposures, and/or lessening the consequences of one or more of the root causes.

In general, three types of recommendations should be generated for each root cause:

1. Correct the specific problem
2. Correct similar existing problems
3. Correct the system that created the problems

Mandatory Performance Activities:

- a. Given event and/or occurrence data, apply problem analysis techniques and identify the problems and how they could have been avoided.**
- b. Participate in at least one contractor or DOE problem analysis and critique the results.**
- c. Given data, interpret a fault tree analysis.**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of these activities.

33. Mechanical systems personnel shall demonstrate a working level knowledge of assessment techniques (such as the planning and use of observations, interviews, and document reviews) to assess facility performance and contractor design and construction activities, report results, and follow up on actions taken as the result of assessments.

- a. Describe the role of mechanical system personnel in the oversight of government-owned, contractor-operated facilities.**

The following is taken from DOE P 226.1B.

To provide strong assurance that the workers, the public, the environment, and national security assets are adequately protected, the Department expects that: 1) robust assurance systems are effectively implemented by site contractors and, for DOE operated activities, by the responsible DOE line management organizations; and 2) DOE oversight is performed effectively by line management, DOE Headquarters and Field, and by independent oversight organizations. Collectively, effective assurance systems and oversight programs provide reasonable assurance that mission objectives are being accomplished without sacrificing adequate protections.

Attributes of effective assurance and oversight processes include: 1) Assurance systems that are tailored to meet the needs and unique risks of each site or activity; methods to perform rigorous self-assessments, conduct feedback, and continuous improvement activities; identification and correction of negative performance trends; and sharing of lessons learned; 2) DOE oversight programs that are designed and conducted commensurate with the level of risk of the activities; and 3) That the oversight of activities with potentially high consequences is given higher priority and greater emphasis.

Effective and properly implemented oversight processes and assurance systems are expected to result in the following:

- DOE Headquarters and Field having assurance that site workers, the public, and the environment are protected while mission objectives are met; contract requirements are fulfilled; and operations, facilities, and systems are being effectively run and continuously improved
- The establishment of metrics and targets for assessing performance and holding managers accountable for achieving their targets
- Improvements in the efficiency and effectiveness of DOE oversight programs by leveraging, when appropriate, the processes and outcomes of contractors' assurance systems

b. Describe the assessment requirements and limitations associated with mechanical system personnel's interface with contractor employees.

As assessment requirements and limitations associated with the interface of mechanical systems personnel and contractor employees vary from site to site, the local Qualifying Official will evaluate the completion of this element.

c. Explain the essential elements of a performance-based assessment, including the areas of investigation, fact-finding, and reporting.

The following is taken from DOE G 414.1-1B.

Performance-based assessments take a different approach than compliance assessments by focusing first on the adequacy of the process that produced a product or service, and then on the product itself. If problems are found in the product or work processes, the assessor evaluates the methods and procedures used to implement the applicable requirements in an effort to find the failure that led to the problems.

The assessor is expected to determine whether a non-compliance or series of non-compliances with procedures could result in a failure to satisfy top-level requirements. Results of prior compliance assessments may help the assessor in determining the focus areas for planning performance-based assessments.

In performance-based assessments, great emphasis is placed on getting the full story on a problem before coming to a conclusion. If an assessor sees a problem with the execution of a welding process, the next step should determine the extent of the problem. Is it limited to one welder? Is it limited to one process? Can the problem be traced to the qualification program for the welder or to the qualification program for the welding process? Or is there a problem with the weld material itself, indicating a problem in the area of engineering or procurement?

While the assessor should be familiar with requirements and procedures, in performance-based assessments the assessor's experience and knowledge play an integral part in determining whether requirements are satisfied. Therefore, participants in performance-based assessments should be technically competent in the areas they are assessing. For example, if an assessor is evaluating a welding process, the assessor relies heavily on his or her knowledge of welding codes, welding processes, and metallurgy, rather than just verifying simple procedure compliance.

Performance-based assessments usually provide the most useful information to management; however, they require a much higher level of competence on the part of the assessment team. Results of performance-based assessments may provide useful insight for management's pursuit of excellence.

The following is taken from DOE-NE-STD-1004-92 (archived).

Investigation

It is important to begin the investigation as soon as an assessment is called for to ensure that data is not lost. The information that should be collected consists of conditions before, during, and after operation of the facility; personnel involvement; environmental factors; and other information having relevance to the operation of the facility.

Fact Finding

Once all the data has been collected, it should be verified to ensure accuracy. The investigation may be enhanced if some physical evidence is retained. Establishing a quarantine area, or the tagging and segregation of pieces and material, should be performed for failed equipment or components. The basic need is to determine the direct, contributing, and root causes so that effective corrective actions can be taken that will prevent recurrence. Areas to be considered when determining what information is needed include

- activities related to the operations of the facility
- initial or recurring problems
- hardware (equipment) or software (programmatic-type issues) associated with the facility
- recent administrative program or equipment changes
- physical environment or circumstances

Methods of gathering information include conducting interviews and collecting statements. Interviews must be factual. Preparing questions before the interview is essential to ensure that all necessary information is obtained. Interviews should be conducted, preferably in person, with those people who are most familiar with the system. Individual statements could be obtained if time or the number of personnel involved makes interviewing impractical. Interviews can be documented using any format desired by the interviewer. Consider conducting a walk-through of the system or facility as part of the interview if time permits.

Reporting

The following is taken from DOE G 414.1-1B.

The results of assessment performance should be documented and transmitted to appropriate management levels. Similar to assessment plans, formality of documentation can vary widely from a memo for small simple scope independent assessments to reviewed, approved, and distributed reports. In general, the following elements should be addressed:

- Executive summary
 - Assessment scope
 - Identification of team members
 - Identification of personnel contacted
 - Documents reviewed
 - Work performance observed
 - Assessment process and criteria
 - Results of the assessment including identification of deficiencies and/or strengths
- d. Explain the essential elements of a performance-based assessment, including investigation, fact-finding, and reporting. Include a discussion of the essential elements and processes of the following assessment activities:**
- **Exit interviews**
 - **Closure process**
 - **Tracking to closure**
 - **Follow-up**
 - **Contractor corrective action implementation**

Exit Interviews

The following is taken from DOE G 414.1-1B.

The exit interview is used primarily by the assessment team to present the assessment summary. Reasonable time should be allowed to discuss any concerns, but this meeting should not be used to argue the assessment findings or methodology. There should be no surprises during the exit meeting since the assessment team should have made every possible effort during the conduct of the assessment to ensure that the assessed organization was aware of the team's findings and concerns. Prior to the exit meeting the assessment team should consider combining related findings into a small number of well-supported findings to help focus management's opportunities for improvement.

Closure Process

The following is taken from DOE G 414.1-5.

Upon completion and implementation of corrective actions, the next step consists of verifying the completion of corrective actions for each finding, and determining effectiveness of the corrective actions in successfully resolving and preventing recurrence of each finding.

One of the most significant problems and most frequently cited weaknesses in the QAP is the lack of follow-up to determine the effectiveness of corrective actions in successfully resolving and preventing recurrence of identified problem findings.

Follow-up

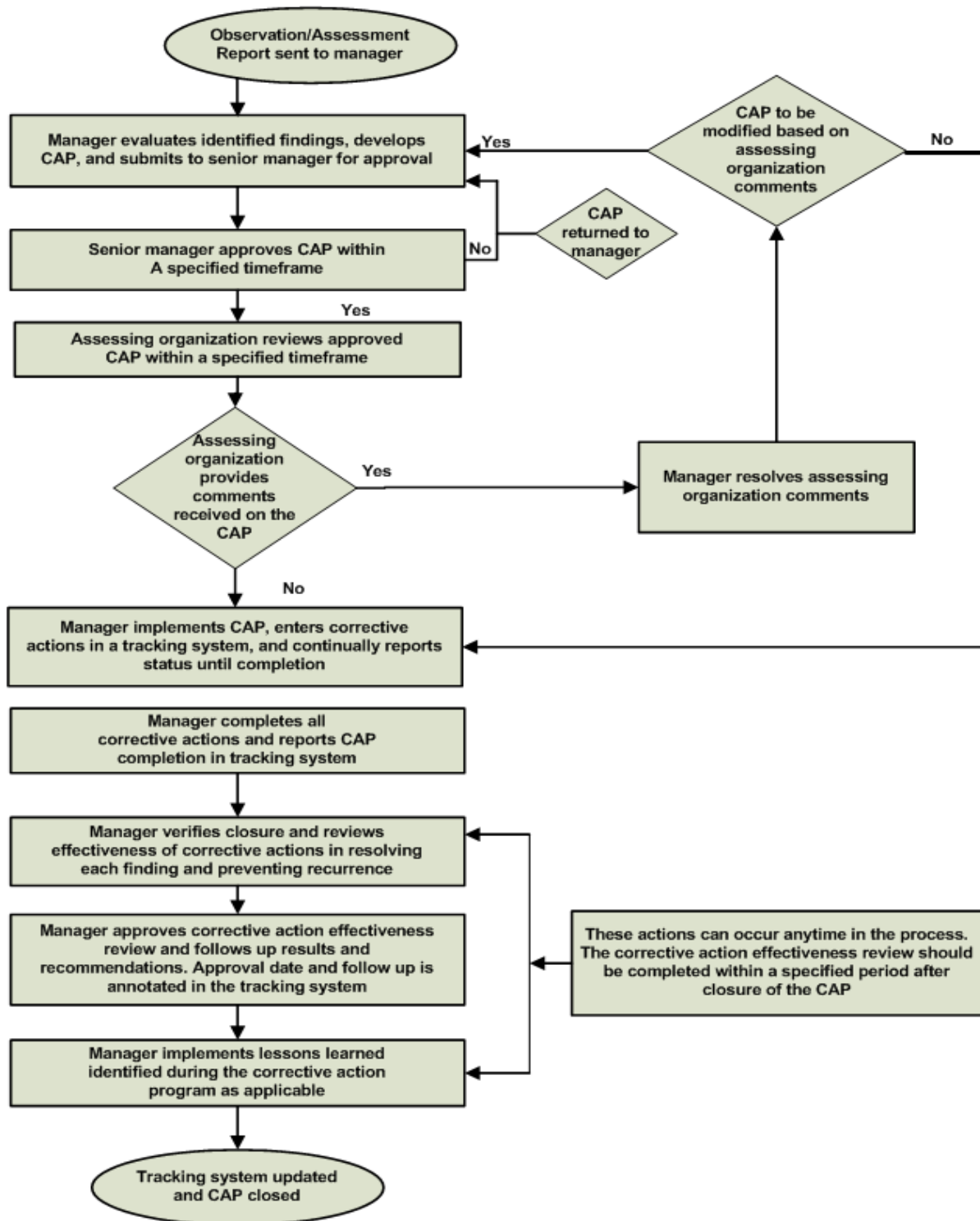
The following is taken from DOE G 414.1-5.

A follow-up assessment with special focus may be performed and should be completed in accordance with applicable corrective action documents. Particularly, this follow-up assessment should evaluate the effectiveness of corrective actions. A reasonable subset of corrective actions should be reviewed for effectiveness.

Contractor Corrective Action Implementation

The following is taken from DOE G 414.1-5.

In summary, the generalized procedures for development, implementation, completion, and follow-up of a corrective action program are illustrated in figure 92.



Source: DOE G 414.1-5

Figure 92. Corrective action program process

The extent and degree of implementing each of these procedures explained in the following is at the discretion of management based on a graded approach of the significance and criticality of the identified problem finding.

They include the following:

- Upon receipt of an event, observation, or assessment report, the manager responsible for the site/organization conducts a thorough evaluation of the reported findings and determines the causal factors contributing to each.
- Based on the results of the finding evaluation, a comprehensive corrective action plan (CAP) should be developed listing the corrective actions to address each finding in the report.
- The CAP should be submitted for approval by the senior manager authorized to provide the resources necessary to implement the corrective actions successfully. A specified timeframe for development and senior manager approval of the CAP should be included in the corrective action process. The DOE Corrective Action Management Program requires Secretarial Officer approval within 60 calendar days from the date of the transmittal forwarding the assessment report.
- The senior manager approves the CAP. If the senior manager does not approve the CAP, it should be returned to the site/organization manager for follow-up action and be resubmitted to the senior manager. Upon approval of the CAP, the site/organization manager should forward a copy to the organization/individual that conducted the assessment/observation for review and feedback. If the assessing organization/individual provides comments concerning the CAP, they should be reviewed by the site/organization manager who will determine if any modifications of the CAP should be made based on the comments. Major modifications involving additional resources may need to be reviewed for approval by the senior manager.
- The responsible site/organization manager implements the approved CAP, enters the findings and associated corrective actions into a tracking system, and ensures the status of corrective actions is effectively tracked and continuously updated to closure.
- Upon completion of all corrective actions in the CAP, the responsible site/organization manager reports completion in the corrective action program tracking system.
- The responsible site/organization manager conducts an independent review of the completed corrective actions implemented for each finding to objectively verify closure and ensure that each finding was effectively resolved and will not recur.
- New or revised CAPs should be documented, approved by the site/organization manager, tracked, and status reported to completion. Upon completion of the revised or new corrective actions for each problem finding, a corrective action effectiveness review of the corrective actions for the specific findings should be conducted, approved and followed up.
- The responsible site/organization manager approves the corrective action effectiveness review and follows up results and recommendations of the review. This may include implementing additional courses of action for partially effective and ineffective corrective actions. The manager should annotate approval and results of the review in the CAP tracking system. Depending on the extent of additional corrective actions determined, the site/organization manager may decide to develop a revised or additional

CAP and conduct another corrective action effectiveness review of the new corrective actions for the specific findings.

- The responsible site/organization manager develops and applies lessons learned identified from the observation/assessment findings; corrective actions in response to the findings; and results of the corrective action effectiveness reviews, as applicable. Implementation of lessons learned may occur at any time during the corrective action program process.
- Upon reporting approval of the corrective action effectiveness review and completion of follow-up activities, the responsible site/organization manager closes the CAP.

e. Describe the actions to be taken if a contractor challenges assessment findings and explain how such challenges can be avoided.

Disputes over the assessment findings or the corrective action plan or its implementation (such as timeliness or adequacy) must be resolved at the lowest possible organizational level. The organization that disagrees with the disposition of a given issue may elevate the dispute for timely resolution. The organization that disagrees with the disposition of a given issue must elevate the dispute in a step-wise manner through the management hierarchy. The dispute must be raised via a deliberate and timely dispute resolution process that provides each party with equal opportunity for input and a subsequent opportunity to appeal decisions up to the Secretary of Energy, if necessary.

f. Discuss the graded approach process that Department line management uses to determine an appropriate level of coverage by mechanical system personnel. Include in this discussion the factors that may influence the level of coverage.

The following is taken from DOE M 426.1-1A.

Determination of the number of staff members to be assigned and qualified at the Federal level begins with the identification of safety systems and safety management programs at each site as relied upon in the DSA. The facility hazard classification; safety classification, number, type, complexity, and accessibility of safety systems; programmatic importance and potential environmental, safety, health, and/or financial impact of facility systems; and maturity and effectiveness of implementation of the contractor's maintenance and safety management programs are used to determine the need for Federal employees with this expertise.

In some cases, it may be prudent to share these responsibilities between field elements and/or facilities, depending on the commonality of system designs, program features, physical location, or life-cycle stage (e.g., startup, decommissioning, closed). Additionally, to the degree these employees may be promoted or otherwise lost from the program, necessary steps should be taken to ensure departing staff members are replaced in a timely manner. The assignment of backups and in-progress qualification for planned replacements should be considered.

Mandatory Performance Activities:

- a. Participate in at least two performance-based assessments as a team member.**
- b. Participate in at least one performance-based assessment as a team leader.**

Mandatory performance activities are performance based. The Qualifying Official will evaluate the completion of these activities.

34. Mechanical systems personnel shall demonstrate a working level knowledge of the safety and health fundamentals of mechanical systems and/or components.

The following is taken from DOE-HDBK-1015/2-93, unless stated otherwise.

a. Discuss the hazards associated with the use of corrosives (acids and alkalies).

Acids

Acids are compounds of hydrogen and one or more other elements (with the exception of carbon) that dissociate or break down to produce hydrogen ions (H^+) when dissolved in water or certain other solvents.

Acids are corrosive in any form, and in high concentrations destroy body tissue and cause severe burns on contact with the skin. The eyes are very susceptible, and permanent damage or loss of sight may result from contact with acids. The inhalation of excessive concentrations of vapor or mist is extremely irritating to the respiratory system and to mucous membranes in particular. Accidental swallowing of concentrated acids may result in severe irritation of and damage to the throat and stomach, which in some cases may prove fatal. Some of these materials are specifically poisonous as well as irritating. In lower concentrations, repeated skin contact may result in inflammation.

Concentrated aqueous solutions of acids are not in themselves flammable. The potential hazard is the danger of their mixture with other chemicals or combustible materials, which may result in fire or explosion. Acids also react with many metals, resulting in the liberation of hydrogen, a highly flammable gas, which upon ignition in air may cause an explosion. Some of the acids are strong oxidizing agents and can react destructively and violently when in contact with organic or other oxidizable materials.

Personnel exposure requiring immediate action usually involves direct contact of the acid with the body or eyes of the individual, inhalation of acid vapors or decomposition products, and ingestion of acid. The initial treatment in all cases of local contact is immediate removal of the acid with a large amount of water. This treatment must be prolonged until all traces of acid have been removed, usually a minimum washing time of 15 minutes.

Alkalies

Alkalies (bases) are corrosive caustic substances that dissociate in water and yield hydroxyl ions. Alkalies include ammonia, ammonium hydroxide; calcium hydroxide and oxide; potassium, potassium hydroxide and carbonate; sodium, sodium hydroxide; carbonate, peroxide and silicate; and trisodium phosphate.

The alkalies, whether in solid form or concentrated liquid solution, are more destructive to tissue than most acids. Alkali dusts, mists, and sprays may cause irritation of the eyes and respiratory tract and lesions of the nasal septum. Strong alkalies combine with tissue, causing severe burns, frequently deep ulceration, and ultimate scarring. Severe burns result not only from contact with solid alkalies, but also from solutions of these compounds. Potassium and sodium hydroxide are the most active materials in this group. Even dilute solutions of the stronger alkalies tend to soften the epidermis (skin) and emulsify or dissolve the skin fats. Exposure to atmospheres contaminated with alkalies may result in damage to the upper respiratory tract and to lung tissue, depending upon the severity of the exposure. The effects of

inhalation may vary from mild irritation of the nasal mucous membranes to severe inflammation of the lungs.

Ingestion causes severe damage to mucous membranes or deeper tissues with which contact is made. Perforation of these tissues may follow, or there may be severe and extensive scar formation. Death may result if penetration into vital areas occurs.

Even though alkalis are not flammable and will not support combustion, much heat is evolved when the solid material is dissolved in water. Therefore, cold water must be used to dissolve solid alkalis, otherwise the solution may boil, and splatter corrosive liquid over a wide area.

b. Describe the general safety precautions required for the handling, storage, and disposal of corrosives.

Corrosives are available in numerous forms and varying concentrations. Some forms and concentrations are more hazardous than others, but the potential for serious accidents exists regardless of the substance in question.

Many of the safety precautions necessary for safe handling and storage are equally applicable to acids and alkalis. Some of the more common precautions are contained in this section. These precautions are not all inclusive, nor are they meant to be. Specific corrosives may require specific precautions, and the MSDS must be consulted in all cases.

Safety in handling hazardous chemicals depends to a great extent upon effective employee education, proper safety practices, intelligent supervision, and the use of safe equipment. Workers should be thoroughly informed of the hazards that may result from improper handling. Each employee should know what to do in an emergency and should be fully informed about proper first-aid measures. Hazards from spills and leaks should be minimized by an adequate supply of water for washing-down. Drainage of hard-surfaced or diked areas should be directed to minimize the exposure of personnel and equipment. Adequate ventilation should be provided in areas where chemical mist or dust is present.

Alkalis are much more injurious to the eyes than acids because strong acids tend to precipitate a protein barrier, which prevents further penetration into the tissue. The alkalis do not do this. They continue to soak into the tissue as long as they are allowed to remain in contact with the eye. The end result of a corrosive burn to the eye (alkali or acid) is usually a scar on the cornea and possible permanent damage.

Speed in removing corrosives is of primary importance. If the chemical enters the eyes, they should be copiously irrigated with water for at least 15 minutes, and a physician should be consulted immediately. In case of contact with skin or mucous membranes, the safety shower should be used immediately. Clothing can be removed under the shower. Contaminated skin areas should be washed with very large quantities of water for 1 to 2 hours, or until medical help arrives. The ready availability of water, particularly safety showers and eye-washing baths, greatly minimizes the possibility of severe, extensive damage. Contaminated clothing and shoes should be thoroughly washed and decontaminated before re-use.

The use of personal protective equipment is not intended as a substitute for adequate control measures, but because corrosives can cause extensive damage to the body, this equipment must be available as needed. During handling operations where spills or splashes are possible, whole body protection (eyes, head, body, hands, and feet) may be necessary. All personal protective

equipment should be carefully cleaned and stored following use, and any equipment that cannot be decontaminated should be discarded.

For the protection of the eyes, chemical safety goggles should be worn. Face shields should be worn if complete face protection is necessary. Eyewash fountains and safety showers must be available at any location where eye and/or skin contact may occur. Protection against mist or dust can be provided by proper respiratory protective equipment. The wearing of protective clothing is also advisable to avoid skin contact. This may consist of rubber gloves, aprons, shoes or boots, and cotton coveralls that fit snugly. Safety shoes or boots made of rubber, chlorobutadiene, or other chemical-resistant materials with built-in steel toecaps are recommended for workers handling drums or in process areas where leakage may occur.

Containers should be stored in rooms with trapped floor drains. Curbs or a drained gutter, covered with an appropriate grill, should be constructed at door openings where floor drains are not provided.

Tanks should be entered for cleaning or repairing only after they have been drained, flushed thoroughly with water, ventilated, and sampled. Workers entering tanks should be monitored by someone on the outside of the tank. A supplied-air respirator or self-contained breathing apparatus, together with rescue harness and lifeline, should be on hand for rescue purposes.

Removal from exposure is the primary and most important step where exposure by inhalation is involved. The individual should be made as warm and comfortable as possible, and a physician should be called immediately.

Ingestion, the least common mode of contamination, requires immediate medical attention. Any attempt at first aid beyond drinking large quantities of water should be made only upon the advice of a physician.

If body burns are severe or extensive, or if the eyes are in any way involved, a physician should be consulted as soon as possible after first aid is rendered. No attempt should be made to neutralize the corrosive prior to treatment with water. Any treatment, in addition to the use of water, should be undertaken only with the advice of the physician.

When corrosives are shipped in small containers such as glass or polyethylene bottles, they should be well protected, whether individually packaged or several are packaged in a single case. After careful inspection, the corrosives may be stored in these containers if the containers are maintained in an upright position and under cover. The containers should be kept off the floor on materials that are corrosive resistant, or protected with corrosive-resistant coverings, to facilitate flushing and other cleanup procedures in the event of leakage or spills.

All drums should be stored on individual racks or securely blocked on skids, with the closure (plug) up to prevent leakage. Drums containing corrosives in liquid form should be vented when received, and at least weekly thereafter, to relieve accumulated internal pressure.

Cylinders should be stored in an upright position, preferably in individual racks and with the valve protective cap in place. In all cases, to avoid error, empty and full containers should be stored in different locations.

Under no circumstance should corrosives be transferred from the original labeled container to an unmarked container. All containers must be labeled clearly, concisely, and in simple, easily

understood terms. Inspection of containers before handling will disclose conditions such as breakage, leakage, and improperly positioned closures which could readily cause a leak or spill.

In handling bottles, barrels, or drums containing corrosives, the following guidelines must be followed:

- Carefully inspect containers prior to handling.
- Use personal protective equipment.
- Use equipment specifically designed for the purpose of transporting and dispensing the chemical in question.
- Label all containers into which the chemical is transferred.

Properties of corrosives make the following considerations mandatory in the selection of a storage site:

- The building, or area within the building selected, should be of fire-resistant construction.
- The floors should be composed of chemical-resistant brick or treated concrete, be washable, and be provided with adequate drainage.
- A well-lit and ventilated area in which there are adequate outlets for water should be provided.
- A relatively cool and dry environment should be maintained, preventing extremes of temperature and humidity.
- Electrical fixtures should be protected against corrosive mists, and wiring should be enclosed and covered with corrosive-resistant material.
- The nature of the corrosive will determine the manner in which it is stored. Most acids should, to some extent, be isolated, some from all other chemicals, some from certain other acids and oxidizable materials such as oil and grease, and some from combustible materials.
- Generally, adequate natural ventilation is sufficient in areas where corrosives are stored, that is, where the containers remain unopened. Where acid is used in work areas where dust or mists may arise (such as in processing equipment or tanks), some form of mechanical exhaust system must be provided.
- Transporting containers within the plant and dispensing at various points throughout the plant are two high-risk procedures that may cause an accident. Proper equipment can be readily obtained, which precludes the necessity of using makeshift or otherwise dangerous methods of transportation.
- Hand trucks or power trucks used for transporting containers should have lifting parts or clamps specially designed for that purpose. If bottles must be transported in the plant or laboratory, they should be enclosed in safety bottle carriers that prevent breakage if the bottle is struck or dropped. All containers (especially acid) must be opened slowly and cautiously because of the possible buildup of pressure within the container. Corrosives may be dispensed from drums by means of siphons, drum transfer pumps, or by gravity with the use of a special fitting, such as a self-closing faucet. Under no circumstances should bottles or drums be subjected to air pressure to expel the contents.
- One final and extremely important consideration is the type of container or receptacle into which corrosives are to be dispensed. The use of an inappropriate or makeshift receptacle can negate the value of all precautionary measures.

- These receptacles may be used for temporary storage or merely as a means of transporting from storage area to place of use. In any event, an appropriate receptacle meets several conditions
 - it is designed for the application;
 - it is used for no other purpose than that for which it is intended; and
 - it is maintained in a safe, clean, and dry condition.

c. Discuss the general safety precautions regarding toxic compounds.

There are general precautions that should be universally employed regarding toxic compounds. Many of these precautions are consistent with those already mentioned concerning corrosives. Proper ventilation, appropriate hygienic practices, housekeeping, protective clothing, and training for safe handling and storage will diminish many of the hazards that exist.

d. Describe the criteria used to determine if a compound is a health hazard and discuss the ways toxic compounds may enter the body.

The toxicity of a material is not synonymous with its health hazard. Toxicity is the capacity of a material to produce injury or harm to a living organism.

Hazard is the possibility that a material will cause injury when a specific quantity is used under specific conditions. Several key elements are considered when evaluating a health hazard:

- Toxicity of the materials used
- Physical properties of these materials
- Absorption probabilities of these materials by individuals
- Extent and intensity of exposure to these materials
- Control measures used

Toxicity is relative. It refers to a harmful effect on some biologic mechanism. The term “toxicity” is commonly used in comparing one chemical agent with another, but such comparison is meaningless if the biologic mechanism, and the conditions under which the harmful effects occur, are not specified.

Although the toxic effects of many chemical agents used in industry are well known, the toxic effects of many other commonly used chemical agents are not as well defined. The toxicity of a material is not a physical constant (such as boiling point, melting point, or temperature); therefore, only a general statement can be made concerning the harmful nature of a given chemical agent.

Many chemical agents are nonselective in their action on tissue or cells; they may exert a harmful effect on all living matter. Other chemical agents may act only on specific cells. Another agent may be harmful only to certain species; other species may have built-in protective devices.

The degree to which a substance will affect living cells can be measured only after recognizable changes have occurred following absorption. Some changes (impaired judgment, delayed reaction time) may be produced at levels too low to cause actual cell damage. Toxicity is dependent upon the dose, rate, method, and site of absorption, and many other factors, including general state of health, individual differences, tolerance, diet, and temperature.

In general, industrial poisonings usually result from inhalation, ingestion, and absorption:

- The inhalation and absorption of toxic agents by the lungs is dependent upon the solubility in body fluids, the diffusion through the lungs, the volume of inhalation, the volume of blood in the lungs, and the concentration gradient of vapors between the inhaled air and the blood.
- Ingestion of the toxic agent can occur to some extent; however, there would generally be considerable inhalation of the material where such conditions exist.
- Absorption through the skin can occur upon exposure to some toxic agents. Some liquids and vapors are known to pass through the skin in concentrations high enough that respiratory protection is not adequate. For example, hydrogen cyanide is known to pass through the unbroken skin. Consideration should be given to the type of work clothes being worn; if they become saturated with solvents, they will act as a reservoir to bathe the body continually with the harmful material.

Most volatile (easily vaporized) organic compounds are eliminated from the body in a matter of hours or, at most, days. Many of the poisonous elements, however, can be stored for long periods of time in various parts of the body. Chronic (long-term) toxicity damage is unlikely to have an even distribution throughout the body. In toxicity studies with radioactive isotopes, the organ which suffers the most severe damage and appears to contribute most to the toxic effect on the body as a whole is called the critical organ. The particular organ that shows the largest amount of damage is the one that is chosen for estimating the effect.

Industrial poisoning may be classified as either acute or chronic. The classification is based on the rate of intake of harmful materials, rate of onset of symptoms, and the duration of symptoms.

Acute poisoning is characterized by rapid absorption of the material and sudden, severe exposure. For example, inhaling high levels of carbon monoxide or swallowing a large quantity of cyanide compound will produce acute poisoning. Generally, acute poisoning results from a single dose that is rapidly absorbed and damages one or more of the vital physiological processes. The development of cancer long after recovery from acute radiation damage is called a delayed acute effect.

Chronic poisoning is characterized by absorption of a harmful material in small doses over a long period of time; each dose, if taken alone, would barely be effective. In chronic poisoning, the harmful materials remain in the tissues, continually injuring a body process. The symptoms in chronic poisoning are usually different from the symptoms seen in acute poisoning by the same toxic agent.

The Occupational Safety and Health Act of 1970 requires that the Department of Health and Human Services publish at least annually, a list of all known toxic substances by generic family, or other useful grouping, and the concentrations at which such toxicity is known to occur. Under the OSH Act, the Secretary of Labor must issue regulations requiring employers to monitor employee exposure to toxic materials and to keep records of any such exposure.

The purpose of the Toxic Substances List is to identify “all known toxic substances” in accordance with definitions that may be used by all sections of our society to describe toxicity.

It must be emphatically stated that the presence of a substance on the list does not automatically mean that it is to be avoided. A listing does mean, however, that the substance has the

documented potential of being hazardous if misused; therefore, care must be exercised to prevent tragic consequences.

The absence of a substance from the list does not necessarily indicate that a substance is not toxic. Some hazardous substances may not qualify for the list because the dose that causes the toxic effect is not known.

Other chemicals associated with skin sensitization and carcinogenicity (ability to cause cancer) may be omitted from the list, because these effects have not been reproduced in experimental animals or because the human data is not definitive.

It is not the purpose of the list to quantify the hazard by way of the toxic concentration or dose that is presented with each of the substances listed. Hazard evaluation involves far more than the recognition of a toxic substance and knowledge of its relative toxic potency. It involves a measurement of the quantity that is available for absorption by the user, the amount of time that is available for absorption, the frequency with which the exposure occurs, the physical form of the substances, and the presence of other substances, additives, or contaminants (toxic or non-toxic).

The purpose of the MSDS is to ensure the individuals working with chemicals and in the vicinity of chemicals have specific information on these chemicals. This form identifies the chemical by its technical and common name and lists the physical/chemical characteristics and fire, explosion, and reactivity hazards. The second page specifies health hazards and recommends first aid procedures. The safe handling and control measures are also supplied. The MSDS is a very helpful document, and personnel working around chemicals should make it a practice to review these sheets frequently for their own safety.

The Code of Federal Regulations recommends that the hazards of all chemicals produced and imported be evaluated and the information concerning the hazards be transmitted to the employers and employees. The MSDS, labels on containers, and employee training should be part of a comprehensive hazards communication program.

e. Discuss the general safety precautions regarding the use, handling, and storage of compressed gases, including hydrogen, oxygen, and nitrogen.

Compressed and liquefied gases are widely useful due to properties including high heat output in combustion for some gases, high reactivity in chemical processing with other gases, extremely low temperatures available from some gases, and the economy of handling them all in compact form at high pressure or low temperature. These same properties, however, also represent hazards if the gases are not handled with full knowledge and care.

Practically all gases can act as simple asphyxiants by displacing the oxygen in air. The chief precaution taken against this potential hazard is adequate ventilation of all enclosed areas in which unsafe concentrations may build up. A second precaution is to avoid entering unventilated areas that might contain high concentrations of gas without first putting on breathing apparatus with a self-contained or hose-line air supply. A number of gases have characteristic odors that can warn of their presence in air. Others, however, like the atmospheric gases, have no odor or color. Warning labels are required for compressed and liquefied gas shipping containers. Similar warning signs are placed at the approaches to areas in which the gases are regularly stored and used.

Some gases can also have a toxic effect on the human system, through inhalation, through high vapor concentrations, or by liquefied gas coming in contact with the skin or the eyes. Adequate ventilation of enclosed areas serves as the chief precaution against high concentrations of gas. In addition, for unusually toxic gases, automatic devices can be purchased or built to constantly monitor the gas concentration and set off alarms if the concentration approaches a danger point. Precautions against skin or eye contact with liquefied gases that are toxic or very cold, or both, include thorough knowledge and training for all personnel handling such gases, the development of proper procedures and equipment for handling them, and special protective clothing and equipment (for example, protective garments, gloves, and face shields).

With flammable gases, it is necessary to guard against the possibility of fire or explosion. Ventilation, in addition to safe procedures and equipment to detect possible leaks, represents a primary precaution against these hazards. If fire breaks out, suitable fire extinguishing apparatus and preparation will limit damage. Care must also be taken to keep any flammable gas from reaching any source of ignition or heat (such as sparking electrical equipment, sparks struck by ordinary tools, boiler rooms, or open flames).

Oxygen poses a combustible hazard of a special kind. Although oxygen does not ignite, it lowers the ignition point of flammable substances and greatly accelerates combustion. It should not be allowed closer than 10 feet to any flammable substance, including grease and oil, and should be stored no closer than 10 feet to cylinders or tanks containing flammable gases.

Proper storage and handling of containers avoids many possible incidents. Hazards resulting from the rupture of a cylinder or other vessel containing gas at high pressure are protected against by careful and secure handling of containers at all times. For example, cylinders should never be struck nor allowed to fall, because if the cylinder is charged to a high pressure and the cylinder valve is broken off, it could become a projectile. Cylinders should not be dragged or rolled across the floor; they should be moved by a hand truck. Also, when they are upright on a hand truck, floor, or vehicle, they should be chained securely to keep them from falling over. Moreover, cylinders should not be heated to the point at which any part of their outside surface exceeds a temperature of 125°F, and they should never be heated with a torch or other open flame. Similar precautions are taken with larger shipping and storage containers. Initial protection against the possibility of vessel rupture is provided by the demanding requirements and recommendations that compressed gas containers fulfill in their construction, testing, and retesting.

Hydrogen

Hydrogen is the lightest of all elements. Its presence cannot be detected by any of the senses. It is flammable in oxygen or air, and has a flammable range of from 4.1 to 74.2 percent by volume in air. A mixture of 10 to 65 percent hydrogen by volume in air will explode if ignited. Pure hydrogen burns quietly in air with an almost invisible flame, and when burned with pure oxygen, a very high temperature may be reached. Hydrogen will burn readily in chlorine gas and under proper conditions will combine with nitrogen, forming ammonia.

Some chemical reactions produce hydrogen as a byproduct. A lead-acid battery will produce hydrogen when it is being charged. Metallic sodium and potassium are examples of some chemicals that react violently when exposed to water, producing hydrogen, which may flame spontaneously due to the heat of the reaction. Many electroplating processes produce hydrogen. Some chemicals used to remove scale from the water side of boilers give off hydrogen.

Whatever the operation, it is important to know whether hydrogen will be produced, and if so, precautions must be taken to prevent its accumulation and ignition. The precautions to take include adequate ventilation to prevent its accumulation and the elimination of possible sources of ignition. Hydrogen is classified as an asphyxiant.

Nitrogen

Nitrogen makes up more than 78 percent of the earth's atmosphere. It will not burn or support combustion. It cannot be detected by any of the senses, and it is not toxic. Although it is often referred to as an inert gas because it does not oxidize readily, it nevertheless forms many compounds. It is frequently used to inert systems that contain, or have contained, flammable liquids or gases. Inerting a system means replacing the oxygen with an inert gas in order to reduce the possibility of fire or explosion.

Nitrogen is fairly soluble in the blood, and a considerable amount will dissolve in the blood of a person when the air pressure is increased, as in diving, caisson, and some tunnel work. If these employees are not properly decompressed, the dissolved nitrogen escapes from the blood in the form of small bubbles in the bloodstream, which causes intense pain and is often fatal. This disorder is commonly known as the bends.

If a large amount of nitrogen were released into the air of an enclosed space, it could cause a serious oxygen deficiency. Nitrogen is an asphyxiant.

Oxygen

Oxygen supports combustion but does not burn. Even so, it must be considered a potentially hazardous element from a fire hazard standpoint. The results of an enriched oxygen atmosphere include a lowered ignition temperature, an increased flammable range, and an acceleration of the burning rate. Oxygen readily combines with other elements and compounds, with spontaneous ignition in some cases. When oxygen comes in contact with oil, grease, or fuel oils, it may ignite violently. Every possible precaution must be taken to prevent this combination.

Oxygen sustains life, but if pure oxygen were inhaled continuously for extended periods, the reactions in the body would be too rapid and would cause harmful effects. Oxygen should always be referred to as oxygen, and not air, to prevent confusion. It should never be used to run pneumatic equipment because of the possibility of coming in contact with oil that may be inside the equipment. Finally, oxygen valves should be operated slowly. Abruptly starting and stopping oxygen flow may ignite contaminants in the system.

f. Explain the difference between a flammable material and a combustible material.

As defined by OSHA, DOT, and NFPA Standard 30, Flammable and Combustible Liquids Code, a flammable liquid is one having a flash point below 100°F, and having a vapor pressure not exceeding 40 psia at 100°F. Combustible liquids are those with flash points at or above 100°F, but below 200°F. Although combustible liquids do not ignite as easily as flammable liquids, they must be handled with caution because of their ability to ignite under certain conditions. Flammable and combustible liquids are further subdivided by NFPA 30 into classes as follows:

- Class I – Those liquids having flash points below 100°F
- Class II – Those liquids having flash points at or above 100°F and below 140°F
- Class III – Those liquids having flash points above 140°F

g. Describe the general safety precautions regarding the use, handling, and storage of flammable and combustible materials.

Avoid accidental mixture of flammable and combustible liquids. A small amount of a highly volatile substance may lower the flash point of a less volatile substance and form a more flammable mixture. In addition, the lower flash point liquid can act as a fuse to ignite the higher flash point material in the same manner as if it were a flammable mixture.

Fill and discharge lines and openings, as well as control valves associated with flammable and combustible systems, shall be identified by labels, color coding, or both, to prevent mixing different substances. All storage tanks shall be clearly labeled with the name of the contents, and products stored within shall not be intermixed. Transfer lines from different types and classes of flammable products should be kept separate, and preferably, different pumps should be provided for individual products.

For handling quantities of flammable liquids up to 5 gallons, a portable Factory Mutual Engineering Corp.- or Underwriters Laboratory-approved container should be used. The container should be clearly identified by lettering or color code.

Smoking, the carrying of strike-anywhere matches, lighters, and other spark-producing devices should not be permitted in a building or area where flammable liquids are stored, handled, or used. The extent of the restricted area will depend on the type of products handled, the design of the building, local codes, and local conditions.

Suitable NO SMOKING signs should be posted conspicuously in those buildings and areas where smoking is prohibited.

Static electricity is generated by the contact and separation of dissimilar material. For example, static electricity is generated when a fluid flows through a pipe or from an orifice into a tank.

The principal hazards created by static electricity are fire and explosion, which are caused by spark discharges. A point of great danger from a static spark is where a flammable vapor is present in the air, such as the outlet of a flammable liquid fill pipe, at a delivery hose nozzle, near an open flammable liquid container, and around a tank truck fill opening. In the presence of a mechanism for generating a static charge, a spark between two bodies occurs when there is a poor electrical conductive path between them. Hence, grounding or bonding of flammable liquid containers is necessary to prevent static electricity from causing a spark.

The terms “bonding” and “grounding” have sometimes been used interchangeably because of a poor understanding of the terms. Bonding eliminates a difference in potential between objects. Grounding eliminates a difference in potential between an object and ground. Bonding and grounding are effective only when the bonded objects are conductive.

When two objects are bonded, the charges flow freely between the bodies, and there is no difference in their charge. Therefore, the likelihood of sparking between them is eliminated.

Although bonding eliminates a difference in potential between the objects that are bonded, it does not eliminate a difference in potential between these objects and the earth unless one of the objects possesses an adequate conductive path to earth. Therefore, bonding will not eliminate the static charge, but will equalize the potential between the objects bonded so that a spark will not occur between them.

An adequate ground will discharge a charged conductive body continuously and is recommended as a safety measure whenever any doubt exists concerning a situation.

To avoid a spark from discharge of static electricity during flammable liquid filling operations, a wire bond should be provided between the storage container and the container being filled, unless a metallic path between the containers is otherwise present.

Above-ground tanks used for storage of flammable liquids do not have to be grounded unless they are on concrete or on nonconductive supports. Ground wires should be uninsulated so they may be easily inspected for mechanical damage and should never be painted.

Petroleum liquids are capable of building up electrical charges when they (a) flow through piping, (b) are agitated in a tank or a container, or (c) are subjected to vigorous mechanical movement such as spraying or splashing. Proper bonding or grounding of the transfer system usually dissipates this static charge to ground as it is generated. However, rapid flow rates in transfer lines can cause very high electrical potentials on the surface of liquids regardless of vessel grounding. Also, some petroleum liquids are poor conductors of electricity, particularly the pure, refined products, and even though the transfer system is properly grounded, a static charge may build up on the surface of the liquid in the receiving container. The charge accumulates because static electricity cannot flow through the liquid to the grounded metal container as fast as it is being generated. If this accumulated charge builds up high enough, a static spark with sufficient energy to ignite a flammable air-vapor mixture can occur when the liquid level approaches a grounded probe or when a probe is lowered into a tank for sampling or gaging.

This high static charge is usually controlled by reducing the flow rates, avoiding violent splashing with side-flow fill lines, and using relaxation time, which allows time for the static charge to discharge.

When flammable liquids are transferred from one container to another, a means of bonding should be provided between the two conductive containers prior to pouring.

In areas where flammable liquids are stored or used, hose nozzles on steam lines used for cleaning should be bonded to the surface of the vessel or object being cleaned. Also, there should be no insulated conductive objects on which the steam could impinge and induce a static charge accumulation.

Nonconductive materials, such as fabric, rubber, or plastic sheeting, passing through or over rolls will also create charges of static electricity. Static from these materials, as well as static from the belts, can be discharged with grounded metal combs or tinsel collectors. Radioactive substances and static neutralizers using electrical discharges are also employed for this purpose.

Bonding and grounding systems should be checked regularly for electrical continuity. Preferably before each fill, the exposed part of the bonding and ground system should be inspected for parts that have deteriorated because of corrosion or that have otherwise been damaged. Many companies specify that bonds and grounds be constructed of bare-braided flexible wire because it facilitates inspection and prevents broken wires from being concealed.

Electricity becomes a source of ignition where flammable vapors exist if the proper type of electrical equipment for these atmospheres either has not been installed or has not been maintained.

A summary of reports of experimental evidence and practical experience in the petroleum industry shows that no significant increase in fire safety is gained by the use of spark-resistant hand tools in the presence of gasoline and similar hydrocarbon vapors. However, some materials such as carbon disulfide, acetylene, and ethyl ether have very low ignition energy requirements. For these and similar materials, the use of special tools designed to minimize the danger of sparks in hazardous locations can be recognized as a conservative safety measure. Leather-faced, plastic, and wood tools are free from the friction-spark hazard, although metallic particles may possibly become embedded in them.

Flammable and combustible liquids and their vapors may create health hazards from both skin contact and inhalation of toxic vapors. Irritation results from the solvent action of many flammable liquids on the natural skin oils and tissue. A toxic hazard of varying degrees exists in practically all cases, depending on the concentration of the vapor.

Most vapors from flammable and combustible liquids are heavier than air and will flow into pits, tank openings, confined areas, and low places in which they contaminate the normal air, and cause a toxic as well as explosive atmosphere. Oxygen deficiency occurs in closed containers, such as a tank that has been closed for a long time and in which rusting has consumed the oxygen. All containers should be aired and tested for toxic and flammable atmosphere as well as the oxygen level before entry.

Class I and class II liquids should not be kept or stored in a building except in approved containers, within either a storage cabinet or a storage room that does not have an opening that communicates with the public portion of the building. The spring-loaded cover is designed to open in order to relieve internal vapor pressure. Quantities stored in such locations should be limited. They should not be stored so as to limit use of exits, stairways, or areas normally used for the safe egress of people. Neither should they be stored close to stoves or heated pipes, nor exposed to the rays of the sun or other sources of heat.

Losses by evaporation of liquid stored in safety cans at ordinary temperatures are negligible. Storage of flammable and combustible liquids in open containers should not be permitted. Approved containers for flammable liquids should be closed after each use and when empty. Warning labels should be removed from flammable liquid containers when empty (vapor free). Bulk class I liquids should be stored in an underground (buried) tank or outside a building. No outlet from the tank should be inside a building unless it terminates in a special room.

Vehicles used on plant property to transport flammable and combustible liquids in sealed containers should be designed to minimize damage to the containers.

When employees are filling tanks and other containers, they should be sure to allow sufficient vapor space (outage) above the liquid level in order to permit expansion of the liquid with changing temperatures. For example, gasoline expands at the rate of about 1% for each 14 °F rise in temperature. Outage space for gasoline of 2% of the capacity of the tank or compartment is recommended, and permanent high-level markings should be installed.

Storage tanks should be provided with vents. Vent pipes of underground tanks storing class I flammable liquids should terminate outside buildings, higher than the fill pipe opening, and not less than 12 feet above the adjacent ground level. They should discharge vertically upward, and be located so that flammable vapors cannot enter building openings or be trapped under eaves or other obstructions. Vent pipes from underground tanks storing class II or class III liquids

should terminate outside buildings and higher than the fill pipe opening. Vent outlets should be above normal snow level.

Additional information concerning installation, protection, and spacing of storage tanks located above ground, underground, or in areas subject to flooding may be found in the NFPA standards.

Flammable or combustible liquids in sealed containers represent a potential hazard rather than an active hazard—the possibility of fire from without. By the same reasoning, inside storage rooms are undesirable. If they must be used, they should be isolated as much as possible and located at or above ground level. They should not be located over basements and should preferably be along an exterior wall.

Every inside storage room shall be provided with either a gravity (low-level intake) or a continuous mechanical exhaust ventilation system. Mechanical ventilation must be used if class I liquids are contained or dispensed inside the room.

Storage cabinets have specific limits on the amount and class of flammable or combustible liquids that may be stored in them. They must be constructed and sealed so as to be fire resistant. Cabinets shall be labeled conspicuously—**FLAMMABLE—KEEP FIRE AWAY**.

The most advisable storage facility is a separate building set some distance from normally occupied plant areas. The construction can be similar to that specified for inside storage rooms. The types and classes of flammable and combustible liquids stored will determine the best design to be used.

h. Identify and discuss the elements of a mechanical system-related safety program, including the following:

- **Protective equipment**
- **Lockout and tagout**
- **Stored energy**
- **Component labeling**

Protective Equipment

The use of personal protective equipment is not intended as a substitute for adequate control measures, but because corrosives can cause extensive damage to the body this equipment must be available as needed. During handling operations where spills or splashes are possible, whole body protection may be necessary. All personal protective equipment should be carefully cleaned and stored following use, and any equipment that cannot be decontaminated should be discarded.

For the protection of the eyes, chemical safety goggles should be worn. Face shields should be worn if complete face protection is necessary. Eyewash fountains and safety showers must be available at any location where eye and/or skin contact may occur. Protection against mist or dust can be provided by proper respiratory protective equipment. The wearing of protective clothing is also advisable to avoid skin contact. This may consist of rubber gloves, aprons, shoes or boots, and cotton coveralls which fit snugly. Safety shoes or boots made of rubber, chlorobutadiene, or other chemical-resistant materials with built-in steel toecaps are recommended for workers handling drums or in process areas where leakage may occur.

Lockout and Tagout

The following is taken from DOE O 422.1.

The operator must establish and implement operations practices that address the following elements for the installation and removal of lockout/tagouts for the protection of personnel:

- Procedures, roles and responsibilities associated with the development, documentation, review, installation, and removal of a lockout/tagout
- Compliance with Occupational Safety and Health Administration Rules, 29 CFR 1910 and/or 29 CFR 1926, requirements for the protection of workers using lockout/tagout
- Compliance with NFPA Standard 70E electrical safety requirements using lockout/tagout
- Description and control of the tags, locks, lockboxes, chains, and other components used for the lockout/tagout program
- Training and qualification in lockout/tagout and special considerations for DOE facilities, e.g. operational limitations, or seismic issues from the mass of locks or chains

Stored Energy

According to 29 CFR 1910.147, “The Control of Hazardous Energy”, upon application of lockout or tagout devices, all potentially hazardous stored or residual energy should be relieved, disconnected, restrained, or otherwise rendered safe. If stored energy might re-accumulate to a hazardous level, verification of isolation should be continued until the servicing or maintenance is completed.

Component Labeling

The following is taken from DOE O 422.1.

The operator must establish and implement operations practices for clear, accurate equipment labeling, addressing the following elements:

- Components that require a label
- Label information that uniquely identifies components and is consistent with regulations, standards, and facility documents
- Durable and securely attached labels that do not interfere with controls or equipment
- Administrative control of labels, including a process for promptly identifying and replacing lost or damaged labels, preventing unauthorized or incorrect labels, and control of temporary labels

35. Mechanical systems personnel shall demonstrate a working level knowledge of the following engineering design principles:

- **Value engineering**
 - **Systems engineering**
 - **Life-cycle cost**
 - **Reliability**
 - **Availability**
 - **Maintainability**
 - **Human factors**
- a. **Define the following terms:**
- **Value engineering**
 - **Systems engineering**
 - **Life-cycle cost**
 - **Reliability**

- **Availability**
- **Maintainability**
- **Human factors**

Value Engineering

The following is taken from Wikipedia, “Value Engineering.”

Value engineering (VE) is a systematic method to improve the value of goods or products and services by using an examination of function. Value, as defined, is the ratio of function to cost. Value can therefore be increased by either improving the function or reducing the cost. It is a primary tenet of VE that basic functions be preserved and not be reduced as a consequence of pursuing value improvements.

In the United States, VE is specifically spelled out in Public Law 104-106, which states that each executive agency shall establish and maintain cost-effective VE procedures and processes.

Value engineering is sometimes taught within the project management or industrial engineering body of knowledge as a technique in which the value of a system’s outputs is optimized by crafting a mix of performance (function) and costs. In most cases this practice identifies and removes unnecessary expenditures, thereby increasing the value for the manufacturer and/or their customers.

Value engineering follows a structured thought process that is based exclusively on function; what something does, not what it is. For example, a screw driver that is being used to stir a can of paint has a function of mixing the contents of a paint can; not the original use of securing a screw into a screw-hole. In VE, functions are always described in a two word abridgment consisting of an active verb and measurable noun (what is being done—the verb—and what it is being done to—the noun) and to do so in the most non-prescriptive way possible. In the screw driver and can of paint example, the most basic function would be blend liquid, which is less prescriptive than stir paint, which can be seen to limit the action (to stirring) and to limit the application (only considers paint.) This is the basis of what VE refers to as function analysis.

Value engineering uses rational logic (a unique how—why questioning technique) and the analysis of function to identify relationships that increase value. It is considered a quantitative method similar to the scientific method, which focuses on hypothesis/conclusion approaches to test relationships; and operations research, which uses model building to identify predictive relationships.

Value engineering is also referred to as value management or value methodology, and value analysis. VE is above all a structured, problem solving process based on function analysis—understanding something with such clarity that it can be described in two words, the active verb and measurable noun abridgement. For example, the function of a pencil is to make marks. This then facilitates considering what else can make marks. From a spray can, lipstick, a diamond on glass to a stick in the sand, one can then clearly decide upon which alternative solution is most appropriate.

Systems Engineering

The following is taken from Wikipedia, “Systems Engineering.”

Systems engineering is an interdisciplinary field of engineering focusing on how complex engineering projects should be designed and managed over their life cycles. Issues such as

logistics, the coordination of different teams, and automatic control of machinery become more difficult when dealing with large, complex projects. Systems engineering deals with work-processes and tools to manage risks on such projects, and it overlaps with both technical and human-centered disciplines such as control engineering, industrial engineering, organizational studies, and project management.

Life-Cycle Cost

The following is taken from DOE G 430.1-1, chapter 23.

Life-cycle costs (LCCs) are all the anticipated costs associated with a project or program alternative throughout its life. This includes costs from pre-operations through operations or to the end of the alternative.

LCC analysis has had a long tradition in the Department of Defense. It has been applied to virtually every new weapon system proposed or under development. Industry has used LCC to help determine which product will cost less over its life cycle. For example, a research and development (R&D) group has two possible configurations for a new product. Both configurations have the same R&D. One product has a lower manufacturing cost, but higher maintenance and support costs. LCC analysis can help to make decisions about which alternative has the lowest LCC.

Reliability

The following is taken from Wikipedia, “Reliability.”

Reliability engineering is an engineering field that deals with the study, evaluation, and life-cycle management of reliability—the ability of a system or component to perform its required functions under stated conditions for a specified period of time. Reliability engineering is a sub-discipline within systems engineering. Reliability is often measured as probability of failure, frequency of failures, or in terms of availability, a probability derived from reliability and maintainability. Maintainability and maintenance are often important parts of reliability engineering.

Reliability engineering is closely related to safety engineering, in that they use common methods for their analysis and may require input from each other. Reliability engineering focuses on costs of failure caused by system downtime, cost of spares, repair equipment, personnel, and cost of warranty claims. The focus of safety engineering is normally not on cost, but on preserving life and nature, and therefore deals only with particular dangerous system failure modes.

Reliability engineering for complex systems requires a different, more elaborate, systems approach than reliability for non-complex systems. Reliability analysis has important links with function analysis, requirements specification, systems design, hardware design, software design, manufacturing, testing, maintenance, transport, storage, spare parts, operations research, human factors, technical documentation, training and more. Effective reliability engineering requires experience, broad engineering skills and knowledge from many different fields of engineering.

Availability

The following is taken from U.S. Department of Defense (DoD), *Guide for Achieving Reliability, Availability, and Maintainability*.

Availability is a measure of the degree to which an item is in an operable state and can be committed at the start of a mission when the mission is called for at an unknown (random) point in time. Availability as measured by the user is a function of how often failures occur and corrective maintenance is required, how often preventative maintenance is performed, how quickly indicated failures can be isolated and repaired, how quickly preventive maintenance tasks can be performed, and how long logistics support delays contribute to down time.

Maintainability

The following is taken from Wikipedia, “Maintainability.”

In engineering, maintainability is the ease with which a product can be maintained to

- isolate defects or their cause;
- correct defects or their cause;
- meet new requirements;
- make future maintenance easier; and
- cope with a changed environment.

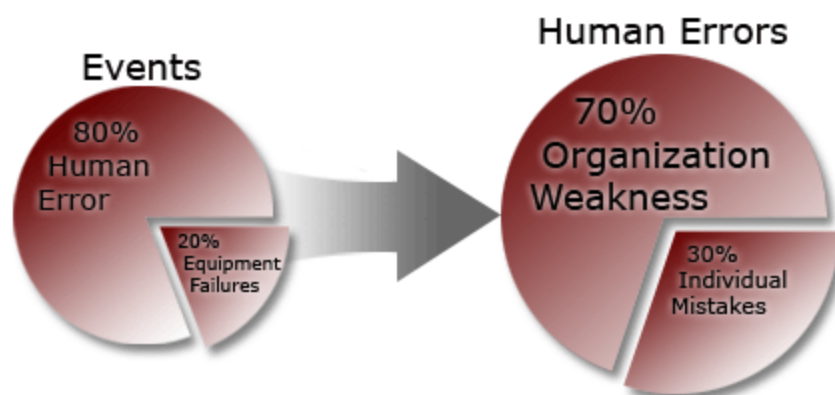
In some cases, maintainability involves a system of continuous improvement—learning from the past in order to improve the ability to maintain systems, or improve reliability of systems based on maintenance experience.

In telecommunication and several other engineering fields, the term maintainability has the following meanings:

- A characteristic of design and installation, expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources
- The ease with which maintenance of a functional unit can be performed in accordance with prescribed requirements

Human Factors

The following is taken from DOE Office of Health, Safety, and Security. “Human Performance Fundamentals: A New Way of Thinking.”



DOE Office of Health, Safety, and Security, Human Performance Fundamentals: A New Way of Thinking

Figure 93. The role of human performance

Figure 93 illustrates what is known about the role of human performance in causing events or occurrences. About 80 percent of all events are initiated by human error. In some industries this number is closer to 90 percent. Roughly 20 percent of

occurrences involve equipment failures. When the 80 percent human error is broken down further it reveals that the majority of errors associated with events stem from latent organizational weaknesses, whereas about 30 percent are caused by the individual worker touching the equipment and systems in the facility.

Clearly, focusing efforts on reducing human error will reduce the probability of occurrences and events.

The traditional belief is that human performance is a worker-focused **phenomenon**. This belief promotes the notion that failures are introduced to the system only through the inherent unreliability of people. “Once we can rid ourselves of a few bad performers, everything will be fine. There is nothing wrong with the system.” However, experience has shown that weaknesses in organizational processes and cultural values are involved in the majority of facility events. Accidents result from a combination of factors beyond the control of the worker. Therefore, the organizational context of human performance is an important consideration. Event-free performance requires an integrated view of human performance from those who attempt to achieve it — that is, how well management, staff, supervisors, and workers function as a team, and the degree of alignment of processes and values in achieving the facility’s economic and safety missions.

b. Describe how the principles of value engineering can be applied to mechanical system projects.

The following is taken from OMB Circular A-131.

Value analysis, value management, and value control are considered synonymous with value engineering (VE). VE is an effective technique for reducing costs, increasing productivity, and improving quality. It can be applied to hardware and software; development, production, and manufacturing; specifications, standards, contract requirements, and other acquisition program documentation; and facilities design and construction. It may be successfully introduced at any point in the life-cycle of products, systems, or procedures. VE is a technique directed toward analyzing the functions of an item or process to determine best value, or the best relationship between worth and cost. In other words, best value is represented by an item or process that consistently performs the required basic function and has the lowest total cost. In this context, the application of VE in facilities construction can yield a better value when construction is approached in a manner that incorporates environmentally-sound and energy-efficient practices and materials.

VE originated in the industrial community, and it has spread to the Federal government due to its potential for yielding a large return on investment. VE has long been recognized as an effective technique to lower the government’s cost while maintaining necessary quality levels. Its most extensive use has been in Federal acquisition programs.

VE is a management tool that can be used alone or with other management techniques and methodologies to improve operations and reduce costs. For example, the total quality management process can include VE and other cost cutting-techniques, such as life-cycle costing, concurrent engineering, and design-to-cost approaches; using these techniques as analytical tools in process and product improvement.

VE contributes to the overall management objectives of streamlining operations, improving quality, reducing costs, and can result in the increased use of environmentally-sound and

energy-efficient practices and materials. The complementary relationship between VE and other management techniques increases the likelihood that overall management objectives are achieved.

c. Explain how life-cycle costs are determined for a mechanical system and how those costs can be used.

The following is taken from DOE G 430.1-1, chapter 23.

LCC analysis is employed to evaluate alternative design configurations, alternative manufacturing methods, alternative support schemes, etc. The LCC process includes

- defining the problem or project (scope)
- defining the requirements of the cost model being used
- collecting historical data/cost relationships/cost data
- defining the schedule
- developing the estimate and analyzing the results

A successful LCC application will

- forecast future resource needs, which when evaluated can identify potential problems or impacts;
- influence R&D or preliminary design decision making; and
- support future strategic planning and budgeting.

d. Explain systems engineering principles and benefits.

The following is taken from Websphere, “The Six Principles of Systems Engineering.”

IBM Rational’s six principles of systems engineering are a set of high-level systems development guidelines derived from the careful analysis of successful, complex systems development engagements over the past ten years.

Although they are neither comprehensive nor mutually exclusive, they serve to highlight key areas of focus for organizations interested in quickly building expertise in complex systems development. They also serve as a measuring stick for assessing potential problem areas and the root causes underlying symptomatic project deficiencies or failures. It is well-known and accepted that function, schedule, and cost are three key and mutually dependent aspects of project management—make a change to one, and the effects often ripple through the other two.

A similar relationship exists in product and program management for complex systems development. The three key aspects are

1. systems architecture;
2. organizational structure, including the systems development infrastructure; and
3. process, including workflows, best practices, and the like.

These aspects collaborate to help achieve the following.

Build the Right System and Build the System Right

Architecture focuses on building the right system, and model-driven, use-case based architectural decomposition lays the foundation for building the system right. Why is architecture singled out? Because it provides the foundation on which the system is ultimately

constructed. The choices made in selecting the system's architecture become a lasting legacy—either good or bad.

Here is a transportation example: the basic architecture used for centuries in building roads or other transportation elements, like rail tracks was basically point-to-point (the shortest distance between two points can be considered optimal since it minimizes the road length and one would assume maximizes time to travel efficiency). Simple enough, but there was always at least one physical constraint: the terrain, which forced the path to avoid obstacles. There were also other potential constraints such as hostile territory or political boundaries.

In any case, roads were built and paths crossed somewhat haphazardly. In the 20th century, population growth generated additional constraints—namely street lights or traffic signs to optimize the flow of traffic through intersections. These are somewhat problematic on roads architected in the point-to-point, avoid obstacle approach, especially where more than two roads intersect. A clearly “better” architecture has proven to be laying out roads in rectangular grids. This architecture and its many implementations are much easier to control from a signaling and traffic flow perspective.

So build the right system and build it right—making it robust (scalable, extendible, easy to maintain, easy to use, and so on).

Do the Right Things, and Do the Things Right

The systems development framework focuses on defining the right things to do throughout the product lifecycle to optimize business value and return on investment. Best practices, processes/supporting tools, and governance (requirements, quality, change, configuration, and program/project management) focus on ensuring things are done right.

Apply the Right Resources, and Apply the Resources Right

Doing and building are action verbs; they require resources to perform the doing and the building. The most significant enterprise resource is people, followed by supporting infrastructure. Acquiring, motivating, and retaining skilled personnel applies the right resources, and aligning the organization appropriately to optimize communication, collaboration, and effort applies the resources optimally. A sound enterprise infrastructure is one key aspect in ensuring the resources are applied optimally, once again maximizing business value and return on investment.

The six principles of systems engineering address all three aspects described above. The three technical principles focus on architecture and the derivation of system models, while the remaining principles provide the complementary infrastructures and workflows needed to optimize the technical development environment.

The six systems engineering development principles are as follows:

1. Decompose systems, not requirements
2. Enable separation and integration of key systems development concerns
3. Specifications flow up and down the architecture
4. Systems and components collaborate; so should development teams
5. Development organizations should reflect product architectures
6. Base the development lifecycle on removing risk and adding value

The principles provide technical guidance for system development teams. They suggest decomposing the system structurally, examining it from multiple viewpoints representing significant areas of concern. They also provide mechanisms to re-integrate the system as a whole, while recognizing that specifications will certainly be discovered not just in the planning and concept stages, but also in design and construction as well. These discoveries will lead to design decisions that may affect more system elements than those contained in the view in which the specification was initially determined, leading to changes up, down, and across the architectural levels.

As systems increase in complexity, greater demands are placed on components and subcomponents. Services are grouped logically to meet functional and supplementary demands, and the interactions between system entities must be adequately described to allow the system to meet its intended purpose. As the model moves from abstract to concrete elements, functions are allocated to software, hardware, firmware, and workers, and the collaborations between elements are finalized.

In hardware/software co-development efforts, collaborations between development teams take on greater importance. Many enterprises align engineers and developers by expertise; software engineers focus primarily on software system elements, hardware engineers may be aligned with functional components, and so on. This alignment can lead to stove piping; that is, narrow bands of specialized knowledge with little interaction across the bands. Although the alignment itself may be a good practice, stove piping is not. Hence our systems engineering principle: Systems and components collaborate, and so should development teams. This often requires direct management focus to encourage and facilitate development team collaborations and to determine the appropriate amount of cross-domain and higher-level resources. An example of this extra management focus might be an enterprise-level systems architecture group encompassing product architectures.

Such a framework and methodology can aid management in facilitating development team collaboration, as can software tools that automate and enforce the collection and management of system development artifacts. The latter are key to capturing design decisions and providing traceability for requirements derivation and allocation across system elements.

Whenever possible, communication and collaborations should be assessed and realigned as needed to support clear, effective, and timely exchange of knowledge and artifacts. One way to do this is to form integrated product teams composed of key product development stakeholders, and to hold regular team meetings to report status and ensure key stakeholder needs are discussed and addressed throughout the development lifecycle.

e. Describe why reliability, availability, and maintainability must be considered in mechanical system design.

The following is taken from DOE-HDBK-1140-2001.

For types of equipment and systems with operating histories, reliability and availability data can aid in identifying failure modes having high cost impacts.

Design for maintainability has as a prime objective the design of systems, subsystems, equipment, and facilities capable of being maintained in the least amount of time, at the lowest cost, and with a minimum expenditure of support resources. Attempts to achieve this objective have evolved into the engineering discipline of maintainability.

To realize the overall goal of maintainability, that is, to prevent failure or to restore a failed system or device to operational effectiveness easily and cost effectively, requires that maintainability and the associated human factors contributions be considered as part of the total design process. Maintainability must be designed into the system and equipment during the beginning stage of development to ensure that costly maintenance and/or redesign are avoided. Maintainability should complement operational requirements of a system. Design for maintainability is an evolutionary process that starts in the equipment concept stage and ends after the equipment has been built and tested.

f. Discuss, in general terms, DOE-HDBK-1140-2001, Human Factors/Ergonomics Handbook for the Design for Ease of Maintenance.

DOE-HDBK-1140-2001 is intended to ensure that DOE systems, subsystems, equipment, and facilities are designed to promote their maintainability. These guidelines are concerned with design features of DOE facilities that can potentially affect preventive and corrective maintenance of systems within DOE facilities. Maintenance includes inspecting, checking, troubleshooting, adjusting, replacing, repairing, and servicing activities. DOE-HDBK-1140-2001 also addresses other factors that influence maintainability, such as repair and maintenance support facilities, including hot shops, maintenance information, and various aspects of the environment and worker health and safety. DOE-HDBK-1140-2001 is to be applied to the system design of DOE systems, subsystems, equipment, and facilities to

- reduce the need for and frequency of design-dictated maintenance;
- reduce system/equipment down-time;
- reduce design-dictated maintenance support costs;
- limit maintenance personnel requirements;
- reduce the potential for maintenance error; and
- assure use of standard procedures, equipment, and tools, when possible.

36. Mechanical systems personnel shall demonstrate a working level knowledge of maintenance management practices related to mechanical systems.

a. Define each of the following maintenance-related terms and explain its relationship to the others:

- **Corrective**
- **Planned**
- **Preventive**
- **Reliability centered**
- **Predictive**

The following definitions are taken from DOE G 433.1-1A.

Corrective

Corrective maintenance is performed in response to failed or malfunctioning equipment, systems, or facilities in order to restore their intended function and design capabilities. Analysis should be performed to determine the causes of unexpected failure and the corrective action that should be taken, including feedback into the preventive and predictive maintenance programs, and training and qualification programs. The establishment of priorities for corrective maintenance should be based on plant objectives and the relative importance of the equipment.

Planned

Planned maintenance is scheduled as a result of periodic maintenance results indicating a future failure.

Preventive

Preventive maintenance (PM) includes periodic and planned actions taken to maintain design capabilities and to extend operating life. Regulatory and code requirements; TSR surveillances, in-service inspection and testing; vendor recommendations; and other forms of maintenance action and frequency selection are based on historical data, engineering judgment, or analytical methods.

Reliability-Centered

Reliability-centered maintenance (RCM) is a structured process commonly used to determine the equipment maintenance strategies required for any physical asset to ensure that it continues to fulfill its intended functions in its present operating context.

Predictive

Predictive maintenance (PdM) consists of measurements or tests performed to detect equipment or system conditions. These activities should be less invasive, time consuming, and costly than preventive or corrective maintenance. The results of PdM can be analyzed to determine what degree of maintenance is required and when it is needed. This provides benefits similar to preventive maintenance without performing unneeded maintenance with its cost and potential for human error. Corrective maintenance efficiency may be improved by directing repair efforts (manpower, tooling, parts) at problems detected using PdM techniques. Industry studies have shown significant savings and improved reliability using PdM. PdM should be integrated into the overall maintenance program so that proactive repair and planned maintenance may be performed before equipment failure.

Not all equipment conditions and failure modes can be reliably monitored; therefore, PdM should be selectively applied. It is normally limited to components and systems that are important to the safe and reliable operation of the facility. The effectiveness of the program is dependent on the accuracy of equipment degradation rate and time to failure assessment.

Many different predictive maintenance techniques are used throughout industry. The following paragraphs describe some of the common predictive maintenance techniques: Although the key elements of the program are applicable to all facilities, some of the details may need to be modified to reflect individual facility conditions and needs.

b. Describe the elements of an effective work control program and the documentation used to control maintenance.

The following is taken from DOE G 433.1-1A.

A maintenance work-control program should be integrated with the planning system and with the integrated safety management system. The work-control program should ensure work activities are consistent with the facility safety basis and effectively identified, initiated, planned, approved, scheduled, coordinated, performed, and reviewed for adequacy and completeness. The program should ensure the availability and operability of the SSCs that are a part of the safety basis. The work-control program should apply the same policies and

procedures for non-facility contractor and subcontractor personnel conducting maintenance on the site as for facility personnel.

The work-control system should provide the data necessary to properly plan and schedule maintenance activities, as well as to support failure analysis and maintenance history.

The maintenance organization should establish high standards for all maintenance personnel supervising and performing maintenance activities. Maintenance management should be involved and oversee work to ensure these standards are met and work is conducted in according to DOE, contractor, and facility policies and procedures.

c. Discuss the importance of maintaining a proper balance of preventive and corrective maintenance.

The following is taken from DOE G 433.1-1A.

An effective maintenance program provides a high degree of equipment and facility predictability, reliability, and cost-effectiveness. Individual equipment maintenance plans may vary, but should be optimized for the equipment. This maintenance approach may range from “Run-to-Failure” for non-safety related, low cost, easily replaceable equipment; to a very proactive plan of ongoing maintenance for equipment whose failure can impact safe operation, product quality, and facility mission. Many factors should be considered in establishing an effective and efficient balance of the various types of maintenance. For safety related systems and equipment, a thorough technical analysis using a method such as RCM should be used to establish this balance. RCM provides a systematic method for analyzing functions, failure modes, and periodic maintenance to monitor and maintain equipment to ensure it continues to meet its functional requirements. For other equipment, the amount of periodic maintenance may be determined through industry experience, consensus standards, and good engineering judgment; then adjusted based upon results during the operating cycle.

d. Define the term “life-limiting component” and discuss its impact on facility operation.

The following is taken from DOE-STD-1073-93.

A life-limiting component is a structure, system, or component whose failure could result in termination of facility operations. Its effect on a facility is the termination of operations until the component can be replaced.

e. Identify typical maintenance performance indicators and discuss their importance.

The following is taken from DOE G 433.1-1A.

Performance monitoring is a valuable management tool to track the reliability of SSC important to safety and the conduct of maintenance. However, the identification of performance indicators, which accurately predict future performance, is challenging. Metrics tend to count results like lost time accidents and PM accomplishment rate. Typically, a goal is set for each metric and possibly a grade or color associated with various performance results. Unfortunately, past performance is not always a reliable indicator of what is to come. Future performance tends to be more a result of behaviors; how workers follow safety rules or provide feedback on inefficient work practices, and how management personnel interact with the staff and receive bad news.

Measuring behavior can be more subjective than objective, but standards should be as well defined as possible.

The selection of core performance indicators should reflect the most important elements of mission and safety performance. The selection of these metrics is itself a message to the organization of what management considers important.

For maintenance, typical indicators include the following:

- Safety
 - Safety system availability
 - LCOs due to equipment failure
 - Total recordable case and days away/restricted time
 - Contamination events
- Quality
 - Equipment availability
 - Maintenance rework
- Production
 - Corrective Maintenance Backlog
 - Overdue PMs

Other examples worthy of consideration include the following:

- Close-Calls – may identify weak work practices, equipment, or procedures
- First Aid Cases – may be an indication of safe work practices
- Overtime Hours – are resources adequate for the work, will backlogs rise
- Personal Protective Equipment (PPE) Infractions – an indication of safety awareness
- Sick Days – may indicate the commitment of the workforce (this should not be associated with specific individuals)
- Self-Assessment Compliance – are supervisors/managers getting into the field, are their observations meaningful (reinforces good practices, discourages bad practices)
- Training Attendance – is training the right priority, are supervisors managing their work to permit attendance

The initial selection of performance indicators should be a thoughtful process involving all the levels of the organization. The selected metrics should be reviewed periodically and modified as necessary to ensure they provide useful data. The metrics and their purpose need to be understood by all.

EFCOG published a Performance Metric Manual in 2002, which explains a performance measurement process piloted at the Savannah River Site. This manual provides a process for metrics, which flow from top to bottom in an organization. Even if not used exactly as described, the manual provides numerous ideas to consider in your own program.

Measuring Performance Indicators

Performance indicators should be sufficiently defined so that their measurement is a simple matter of counting or transcribing from an organization record or log. Even assessment results that may be somewhat subjective can be given a grade useful for comparison. The periodicity of

the data should be thoughtful—typically monthly or quarterly is sufficient. The data should be recorded, retained, and trended over multiple data periods—typically a year or more.

The data should be true and accurate to be of real value in assessing organizational conditions. Established goals should be challenging, but realistic. It would be laudable if an organization never had an occurrence or even a close call, but significant management pressure to achieve that goal may discourage reporting. That is clearly not the desired result. A close call, properly handled, could fix an organizational deficiency that if left unreported could lead to a significant event.

Analyzing Performance Indicators

What is done with performance indicator data is the most important aspect of performance measures. How are changes in data evaluated to be significant or a trend? Some organizations have employed statistical process control techniques to establish data normal and standard deviations – this may be a reasonable approach if there is access to the specialized expertise required to make this meaningful. However, most organizations simply look for changes and the apparent causes, and if other related indicators are consistent. If this condition is considered important by the responsible manager or their boss, they are further analyzed.

The purpose of analyzing changes in performance indicators is to identify the factors causing the indicator to change. There will be obvious factors, however, these are typically superficial; fixing them is not a long-term solution and may hide an error producing condition. There will likely be human performance factors, but the vast majority of these factors are influenced by organizational conditions that affect more than a single individual. Data gathering and analysis and using the event analysis techniques described in the references above should go beyond faultfinding and determine the underlying organizational conditions or processes that should be addressed.

The following factors should be considered in these analyses:

- Availability of physical resources
 - Tools, equipment
 - Spare parts, materials
 - Workers, support personnel
 - Workspace, light, ventilation
 - Sufficient labels, gauges, annunciators, and control devices
 - Availability of tools, materials, technology, equipment, improved lighting, adequate budget, spare parts, etc
 - Adequate predictive/preventive maintenance
- Organization/Facility Structure
 - Clear responsibilities, policies, goals
 - Logical reporting structure
 - Effective configuration management—drawings, procedures, training up-to-date
 - Available support personnel
 - Consistent scheduling and adequate work planning
 - Effective oversight, self-assessment, and supervision
- Information
 - Adequate pre-job brief, turnover

- Clear and accurate maintenance, operating, or special test procedures/instructions
- Accurate and available drawings, equipment manuals, technical specifications
- Adequate time to review work procedure and prepare for task
- Lessons Learned appropriately applied/shared
- Post-maintenance testing verifies equipment operability
- Knowledge/Skills/Abilities
 - Effective qualification program
 - Appropriate worker and supervisor training programs and materials
 - Effective OJT and skills training
 - Proper use of self-check and peer-check
 - Adequate quality assurance and quality control
- Motivation
 - Work schedule reasonable, overtime not excessive
 - Appropriate recognition, bonuses
 - Fair pay, benefits, job security, advancement opportunity, etc.

f. Discuss how maintenance is related to conduct of operations, quality assurance, and configuration management.

Conduct of operations, quality assurance, and configuration management are all aspects of a successful maintenance program. These programs are integrated into all other programs and are the key to success in a maintenance program. Conduct of operations develops the way maintenance is performed, along with the training requirements and methodology applied to maintenance. QA develops the requirements for the maintenance and identifies the maintenance type, whether corrective maintenance, predictive maintenance, or preventive maintenance. QA also ensures that the quality of maintenance is preserved. This program ensures that like-for-like parts are used as necessary. Configuration management allows for planning when the maintenance can be performed. It allows for scheduling shutdowns and maintenance times along with retest times, as needed. The programs all need to overlap to ensure a successful program.

g. Discuss the purpose of reliability, availability, maintainability, and inspectability (RAMI) analyses in the establishment of maintenance requirements.

RAMI analyses are performed to determine the amount of time that needs to be scheduled for maintenance, and to determine failure rates and what needs to be done to maintain the equipment in operating condition with a minimal amount of down time.

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“What is a Cartridge Filter?”
“What is a Seal Weld?”
“What is a Tube Sheet?”
“What is an Evaporator Coil?”
“What is Cavitation?”

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Reference Guide
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